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Institute and Related Activities

Wave Form and Amplification of Corona Discharge

BY J. B. WHITEHEAD AND N. INOUYE

Fellow, A. I. E. E. Associate, A. I. E. E.

Both of Johns Hopkins University

Review of the Subject. *Corona forms on a round wire or cable when the voltage is raised to such a point that the voltage gradient near the wire is sufficiently high to break down the insulating properties of the air. The larger the wire the higher the voltage to cause corona. The corona is luminous and ionizes the air, giving it electrical conductivity; thus corona has the effect of giving the conductor a larger diameter; and since a higher voltage is required for corona on a larger wire, a state of equilibrium is reached and corona is an equilibrium phenomenon not necessarily attended by spark-over.*

Since corona causes conductivity it is a cause of leakage and consequently of loss of power. It also increases temperature and decomposes the air into chemical constituents which are harmful to insulation. Engineers therefore have usually regarded corona as a dangerous phenomenon and one to be avoided by proper design. Transmission lines, for example, for the most part are designed so that their operating voltage is well below that at which corona would be formed on the conductors.

Two suggestions have been made to make use of the properties of corona. The first is as a protective device for transmission lines. Since the corona is conducting and dissipates energy, it has been proposed to operate transmission lines relatively close to the corona-forming voltage. When abnormal rises of voltage due to lightning or other causes occur, corona begins, the air becomes conducting, and the high voltage is relieved. The exact value of corona in this connection is not known, although there is some evidence that it acts in the manner described.

A second use of the corona, suggested by one of the authors of the present paper, is that it be used as a method for measurement of the crest values of high alternating voltages. The corona begins at a sharply marked definite value of voltage, and the laws governing the value are now well-known. The corona voltmeter is an instrument for detecting, either by the sound or by the conductivity of the air occasioned by corona, the exact voltage at which corona begins. The value of the voltage is given in terms of the dimensions of the instrument and the pressure and temperature of the air. The instrument has been described in two earlier papers, in which it is shown that the measurements of voltage with the corona voltmeter are more accurate than by any other method and that the instrument has several other advantages over methods at present in use. The present paper deals with methods for increasing the sensitivity of the corona voltmeter and for adapting the ordinary telephone receiver and standard portable instruments as indicators of the first appearance of corona. The corona discharge current is rectified and also amplified by means of hot cathode tubes. Incidentally the experiments on rectification included a study of the wave form of the discharge due to the alternating corona. It was also found that the sound due to the corona could be amplified so that the first appearance of corona would be indicated on a loud-speaking telephone.

CONTENTS

I. Introduction

THE high-voltgage corona appears at a sharply marked definite value of voltage of a clean round wire. This fact is made use of in the corona voltmeter, the law of corona as affected also by temperature and pressure being now known to a high degree of accuracy. The instrument appears to offer the most accurate method for determining crest values of high alternating voltages.

In addition to the method of visual observation, which is relatively inconvenient, two methods have been used in the corona voltmeter for detecting the first appearance of corona, (a) the telephone, and (b) the continuous-current galvanometer. Both of these devices indicated the first appearance of corona with a high degree of accuracy. Under laboratory conditions either may be used with satisfaction, the telephone being somewhat simpler, and useful for detecting occasional local sparking due to surface imperfections of the corona wire. However, the total volume of corona discharge produces a relatively small current, so a sensitive galvanometer is necessary, more sensitive than can be had in a readily portable type, and requiring usually a telescope and scale. Consequently some inconvenience is occasioned if the voltmeter is to be moved from place to place. Moreover the sound of the corona in the telephone, while clear and sharp in a quiet room, is easily masked by other extraneous noises. It is desirable therefore to develop methods for observing the first appearance of corona on the usual type of portable instrument with direct-reading scale, and also by means of a loud-speaking telephone. Both these things have been accomplished in the experiments described below, thanks to the rectifying and amplifying properties of the three-electrode vacuum tube. In addition some interesting curves showing the wave form of corona discharge have been obtained.

II. Apparatus and Method

The essential elements of the galvanometer method of detecting corona are shown in Fig. 1, in which C, the perforated cylinder in the corona voltmeter, is connected to ground, and the corona wire F is placed in the center of the cylinder. D is a surrounding

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cylinder only slightly larger in diameter than C, from which it is carefully insulated. When corona appears on the central rod F the surrounding air is copiously ionized and this ionization extends through the perforations to the space between the cylinders C and D, which thus becomes highly conducting, resulting in a deflection of the galvanometer G.

The present experiments were all conducted with the corona discharge on a nickel-plated steel rod 0.289 cm. (0.188 in.) in diameter. The sensitive d'Arsonval galvanometer used is of wall type and has an undamped sensitivity of 1280 megohms; when critically damped with a shunt of 3400 ohms the sensitivity is 428 megohms. The resistance R, Fig. 1, of 50,000 ohms was put in series to protect the galvanometer from possible short circuit in the corona voltmeter. The potential of the battery between galvanometer and ground was plus or minus 115 volts.

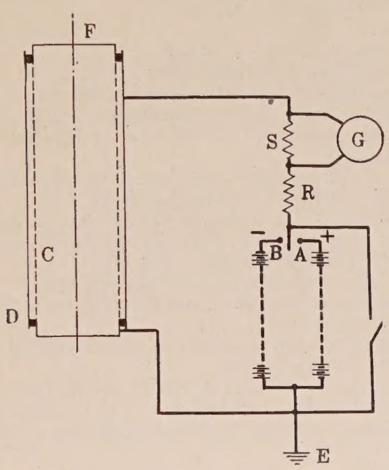


Fig. 1—The Galvanometer as Detector of Corona

The length of the cylinder D was 60.95 cm., its diameter 24.67 cm., and its space separation from the cylinder C 0.317 cm.

The curves in Fig. 2 were taken with the corona rod, 0.289 cm. diameter and plotted with galvanometer deflections in centimeters as ordinates, and transformer tertiary coil volts as abscissa. (See Fig. 3). The ratio of transformation of the high-tension transformer was such that 120 volts on the tertiary coil corresponded to 100,000 volts at the high-voltage terminals. Three curves were taken at atmospheric pressure, one with the electrode D of Fig. 1 at 115 volts positive, one at 115 volts negative, and one at ground potential as shown in Fig. 2.

It is to be noted that negative potential on the electrode D is best for the detection of the first presence of corona, in that the curve rises most sharply. The greater sensitivity of the negative electrode is obviously due to the fact that corona formation or ionization of the air occurs first due to the motion of the negative electron. The acceleration of the electron is greatest when it is moving toward the positively charged corona conductor. Under these circumstances the positive ions, as products of the process of ionization, are repelled and therefore give maximum current in the galvanometer circuit of Fig. 1 when the electrode D is negative.

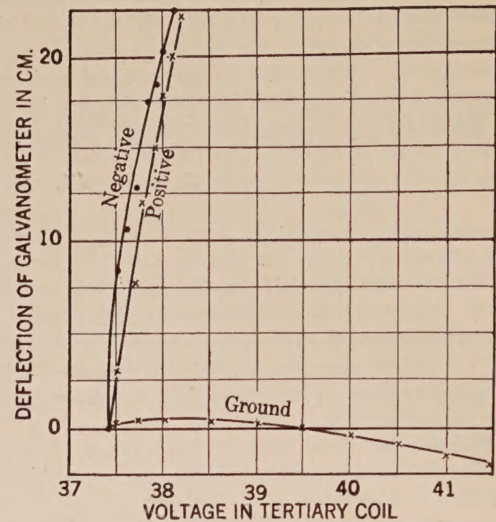


Fig. 2—Galvanometer as Detector of Corona
(0.188 in. = 0.478 cm. diameter rod)
Atmospheric pressure.

III. Galvanometer with Rectifying Valve

a. Wave Form of Corona Discharge. While the curves of Fig. 2 are readily obtainable on sensitive galvanometers, they cannot be taken with even the most sensitive types of direct-reading portable instrument. In considering possible ways of using the discharge with satisfaction on a less sensitive type of instrument it is to be noted at once that in the arrangement of Fig. 1 the deflection of the d'Arsonval galvanometer is proportional to the difference of the mean values of the corona discharge on the positive and negative sides of the wave form. The deflection due to the discharge must therefore be largely due to some difference in the heights of the peaks in the positive and negative

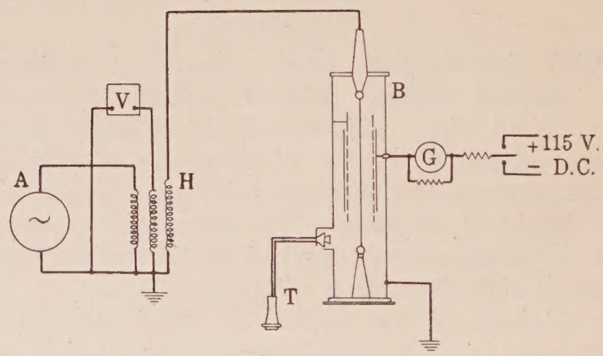


Fig. 3—Principal Connections
A—Alternator,
H—High-tension transformer,
V—Tertiary coil voltmeter,
B—Corona voltmeter,
G—D'Arsonval galvanometer,
T—Telephone receiver.

sides of the discharge current. It is evident therefore that elimination of one-half of the discharge current curve will greatly increase the net unidirectional current in the galvanometer circuit. This can be accomplished either with a synchronous commutator used as suppressor, or more conveniently still, by means of a rectifying vacuum tube. The whole question of the difference between the volume of discharge on the positive and negative sides of the voltage waves is one of great interest. It therefore seemed desirable, from the standpoint of the purpose of the experiments and also from that of the interest of the phenomenon itself, to take a series of wave forms of the corona discharge current.

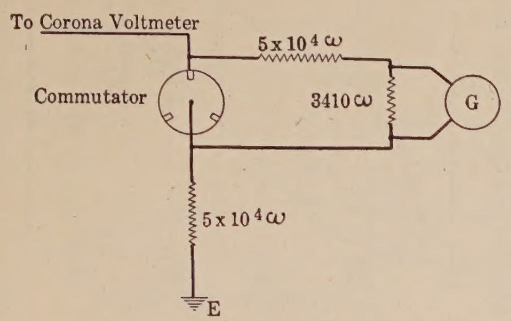


FIG. 4—CONNECTIONS TO STUDY WAVE FORM OF CORONA DISCHARGE

For this purpose a special synchronous commutator was mounted on the shaft of the alternator furnishing the high voltage. In Fig. 4 the commutator was put in shunt to the galvanometer and the discharge current was short-circuited through each full cycle, except for one very short interval. The commutator, Fig. 5, was made of a copper disk, 4¼ in. diameter, with three slots of ¼-in. width filled with hard rubbed placed at intervals of 120 deg., corresponding to half the number of poles of the alternator, and so each giving open circuit at the same position on the wave form. The commutator was insulated from the shaft. Three copper brushes were attached at intervals of 30 deg. on the movable wooden disk; the two outer brushes were connected together to keep continuous contact to the copper disk, and under the middle one the open circuit was given by the three slots on the commutator.

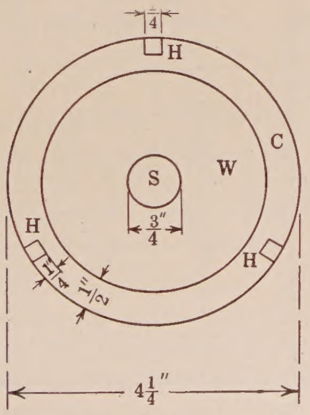


FIG. 5—DIMENSIONS OF COMMUTATOR USED

C—Copper disk,
H—Insulator (hard rubber),
W—Wooden block,
S—Shaft.
Thickness of copper disk: ½ inch.

First, the brush setting was observed corresponding to the maximum value of voltage on the corona wire by shifting the brush to find the point of no charging current in the galvanometer, and it was found to be 30 deg. on the fixed disk, calibrated 360 deg. on the whole circle.

Two wave forms of the currents through the galvanometer circuit were observed for voltages below and above corona formation; the difference of these wave forms must be the wave form of corona discharge. The wave form observed just before the start of corona is the charging current through electrode *D* and the wave form observed just after the start of corona is the superposition of charging current and corona discharge current.

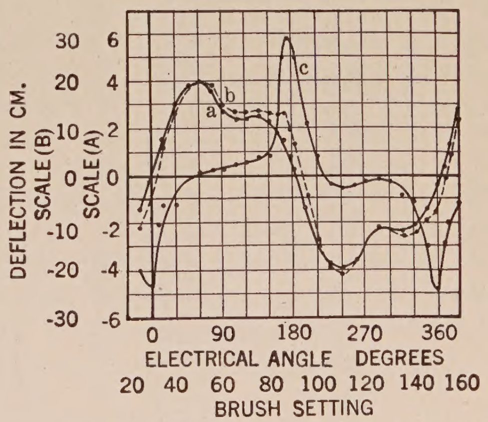


FIG. 6—WAVE FORM OF CORONA DISCHARGE CURRENT ON 0.188-IN. CORONA ROD

(Corona starts at 36.6 volts)
Curve *a*—Charging current (Scale *A*) at 36.5 volts,
Curve *b*—Deformed current (Scale *A*) at 36.6 volts,
Curve *c*—Corona discharge current (Scale *B*)

The observations were taken at atmospheric pressure of 74.77 cm. and room temperature of 18.2 deg. cent. on the corona wire of 0.289-cm. diameter. Readings are shown in Table I; the curves in Fig. 6 are plotted from the same observations; the positive direction of current was from the electrode *D* to ground (Fig. 1.).

From the curves it may be seen that the corona discharge current is of alternating form with a rather peaked shape for each half cycle, but the value of the positive peak is a little higher than that of the negative and this is the reason why the negative electrode is more effective for detecting corona.

b. Rectifying Valve in Detecting Circuit. If we choke off one of the half waves shown in curve *C* of Fig. 6 we have at once a great increase of unidirectional current in the detecting galvanometer circuit. As stated above, the most convenient way of accomplish-

ing this is the rectifying tube or valve of "kenotron" or similar type, which as is well-known passes current from a plate electrode to a heated filament, but completely chokes current from the filament to the plate.

Placing the valve between the galvanometer and the electrode in the corona voltmeter, Fig. 1, we observe at once a great difference in the sensitivities as between the two methods of connecting the valve in the circuit, *i. e.,* (1) the filament of the valve connected to the electrode and the plate to the galvanometer, and (2) the filament to the galvanometer and the plate to the electrode.

In Fig. 7 three curves correspond to the three cases,

TABLE I.
Wave Form of Corona Discharge

Brush setting in degrees	Galvanometer deflections in cm. Before corona	After corona	Corona discharge
25	−6.5	−10.5	−4.0
30	.3	− 4.5	−4.8
35	7.6	6.4	−1.2
40	15.0	13.8	−1.2
45	19.5	19.3	−0.2
50	20.5	20.6	0.1
55	18.5	18.7	0.2
60	14.0	14.2	0.2
65	11.7	12.2	0.5
70	12.1	12.7	0.6
75	12.5	13.3	0.8
80	11.3	12.1	0.8
82.5	9.2	12.0	1.8
85	7.1	12.1	5.0
87.5	4.2	10.1	5.9
90	1.3	6.3	5.0
92.5	− 3.0	1.1	4.1
95	− 6.7	− 4.4	2.3
97.5	−10.9	− 9.8	1.1
100	−13.9	−13.0	0.9
105	−18.8	−19.0	−0.2
110	−19.9	−20.4	−0.5
115	−18.1	−18.5	−0.4
120	−13.4	−13.7	−0.3
125	−10.5	−10.6	−0.1
130	−11.1	−11.3	−0.2
135	−11.8	−12.7	−0.9
140	−10.6	−11.7	−1.1
142.5	− 8.5	− 9.9	−1.4
145	− 6.6	− 9.5	−2.9
147.5	− 4.5	− 8.7	−4.2
150	− 1.2	− 6.1	−4.9
152.5	2.5	− 0.3	−2.8
155	6.8	4.8	−2.0
160	14.6	13.5	−1.1

(a) filament connected to the galvanometer, (b) filament to the electrode, and (c) no valve being used. In each case no continuous potential was used, the galvanometer being connected directly to ground through the high resistance *R*, Fig. 1.

From these results it may be said that the valve with its plate connected to the electrode gives the maximum volume of corona discharge current. This is in agreement with the condition of greatest sensitivity when the valve is not used, namely, negative electrode *D*, or current from electrode to ground. For greater sensitivity we add negative potential of 115 volts on the filament through galvanometer and high resistance by means of a battery of cells. With positive potential on the filament no current was detected, as is to be expected.

Using the same galvanometer with shunt resistance and other conditions unchanged, observations were

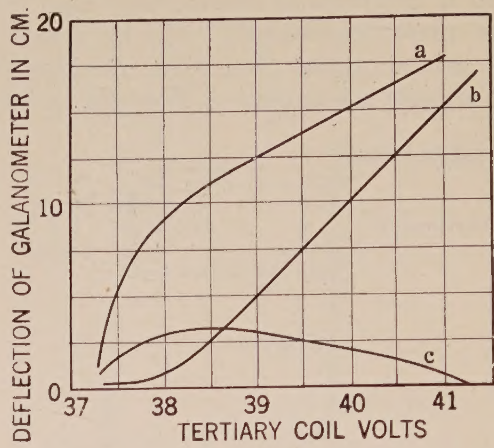


Fig. 7—Galvanometer with Kenotron without any Potential on the Circuit

Curve *a*—Filament of kenotron being connected to the galvanometer,
Curve *b*—Filament to the electrode in the corona voltmeter,
Curve *c*—No kenotron used.

taken of galvanometer deflections corresponding to (a) no potential on valve filament, (b) negative potential 115 volts on valve filament, and (c) positive potential 115 volts on filament, the plate of the valve being connected to the electrode in the corona voltmeter

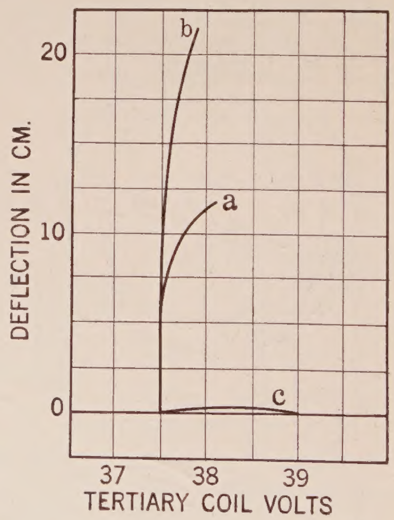
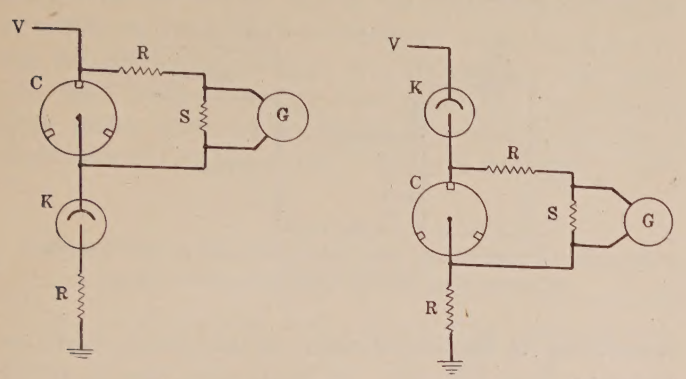


Fig. 8—Galvanometer with Rectifying Valve Potential Applied on the Filament

(Plate of valve connected to the electrode in the corona voltmeter)
Curve *a*—No potential on the filament, this corresponds to the curve (a) in Fig. 7.
Curve *b*—Negative potential on the filament.
Curve *c*—Positive potential on the filament.

in each case and the voltage being gradually raised through the corona forming value. Voltages are given throughout in terms of values at the terminals of the tertiary coils. The results of these tests are given in Fig. 8. The influence of negative potential

on the filament in increasing the sensitivity is very noticeable. The positive potential chokes off the discharge almost completely. From these results it is obvious that the rectifying valve may be used with great satisfaction for increasing the volume of corona discharge as a means of detecting the first presence of corona and that it should be so connected that the



Figs. 9 and 10—Connections showing the Two Positions of Kenotron

C—Commutator,
K—Kenotron,
G—Galvanometer,
S—Shunt resistance (3410 ohms),
R—Resistances (5×10^4 ohms each),
V—Corona voltmeter.

In connection Fig. 10 we found no charging current on the wave form of corona discharge current.

plate of the valve is connected to the electrode in the corona voltmeter.

c. Portable Instrument in Place of d'Arsonval Galvanometer. Although the volume of the discharge current is greatly increased by the methods described above, it was found to be not yet sufficient to give satisfactory indications on a portable type of instrument. Tests of this question were made using a Siemens and Halske needle galvanometer having 25 divisions of scale on each side of a central zero, and each division corresponding to 10^{-6} ampere. The resistance of the instrument is 100 ohms.

Using this needle galvanometer with shunt of 9000 ohms in place of the d'Arsonval galvanometer of the earliest experiments, we found a deflection of only 1½ divisions for a voltage 6 per cent above corona-forming value. Ordinarily this excess voltage would give deflections well off the scale using the most sensitive wall-type instrument. In these experiments the filament of the valve was connected through the instrument to the negative terminal of a 115-volt instrument, this being the most sensitive method of connection, as described above.

In view of these results it will be seen that while the rectifying valve has given a great increase in the volume of discharge, this increase is not yet sufficient to permit the use of the common type of portable instrument. If this type of instrument is to be used, some form of amplification of the discharge current must be used. This amplification was accomplished by the use of three-electrode amplifying tubes in the experiments described below.

d. Wave Form of the Rectified Corona Discharge Current. Before applying the usual methods of amplification to the corona discharge current it is important that the rectified corona discharge shall have no reverse current, that is that it shall be strictly unidirectional. Elimination of reverse currents is necessary since the rectifying valve and also the amplifying tube may be overloaded by them and so prevent the amplification of the unidirectional component. For these reasons we investigated the wave form of the rectified current by means of the synchronous commutator, as described above. At first we found large values of charging current in the wave form, these being induced currents arising in the circuit between the galvanometer and ground, and due to the alternating static field. In these measurements the galvanometer was connected directly to the electrode in the corona voltmeter and the valve between the galvanometer and ground, as shown in Fig. 9. After shortening the connections between all parts and changing the positions of the valve and the galvanometer to those shown in Fig. 10, we finally obtained strictly unidirectional current of very irregular wave forms.

The two curves in Fig. 11 were measured by the commutator method described above, the plate of the valve being connected directly to the electrode in the corona voltmeter. First one side of the galvanometer was grounded through the high resistance *R*, and next negative potential of 115 volts was applied

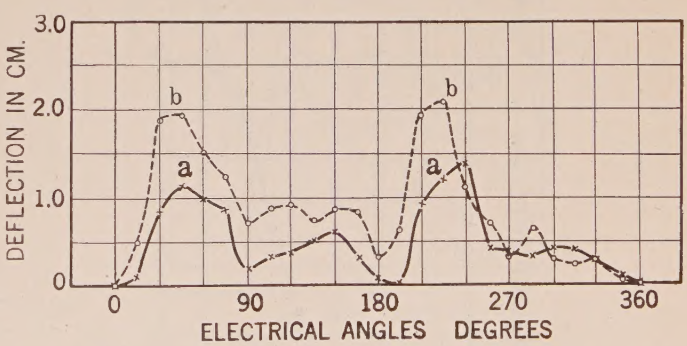


Fig. 11—Wave Forms of Rectified Corona Discharge Currents by the Kenotron

Curve *a*—No potential applied on the filament of the kenotron,
Curve *b*—Negative potential applied on the filament of the kenotron through the galvanometer and the high resistance.

to the filament through the galvanometer and high resistance.

The irregularity of the wave forms shown in Fig. 11 is in some measure due to the continuously changing thermoelectric electromotive force at the brush contacts which is not sufficiently eliminated by the high resistance in series in the galvanometer circuit. (See Fig. 4.) This thermal electromotive force was further eliminated in its effect on the current to be measured by taking the difference of right and left galvanometer deflections both before and after starting corona. It

is probable that the elimination of this effect is not complete and that therefore the curves shown in Fig. 11 are not an exact reproduction of the shape of the corona discharge. They must however approximate it very closely and they show clearly that there is no reverse element in the rectified current. It is sufficient for amplification that there be no reverse current and consequently these experiments were next undertaken.

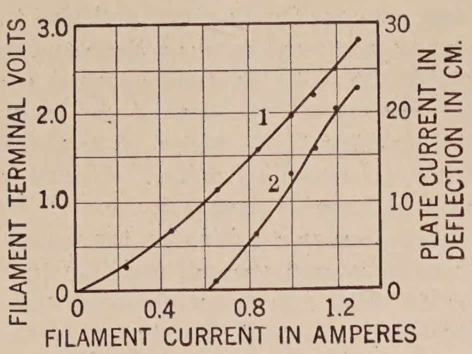


Fig. 12

Curve 1—Filament terminal volts,
Curve 2—Plate current.

IV. Amplification of Corona Discharge Current

a. Characteristic Curves of the Electron Tube. The problem presented is to amplify the unidirectional pulsating current from electrode *D* with an average value of about 10^{-7} ampere to a value which may be read on a conveniently portable instrument, such as the Siemens and Halske needle galvanometer, described

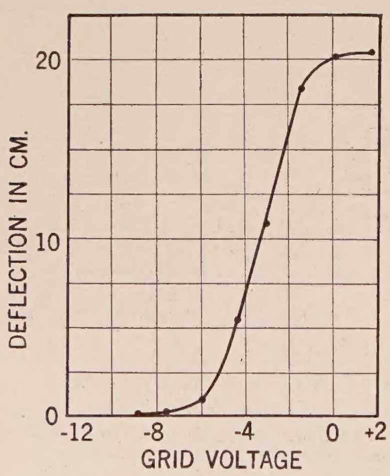


Fig. 13—Plate Current

above. After experiments with several different methods of connection and different tubes, the connections of Fig. 15 were found to be most suitable for our purpose.

One 102-A Western electron tube was used and its characteristic curves were studied. The relation between plate current and filament current with no grid voltage and also the relation between plate current and grid voltage with constant filament current were taken. The curves of Figs. 12 and 13 were taken with a d'Arsonval galvanometer in the plate circuit and with 120 volts on the plate. Fig. 14 shows the method of measuring the relation between plate current and grid voltage. The relation of filament current and plate current is obtained with slight modifications of the connections as shown. The grid leak of 1.5 megohms and a different location of the ground connection

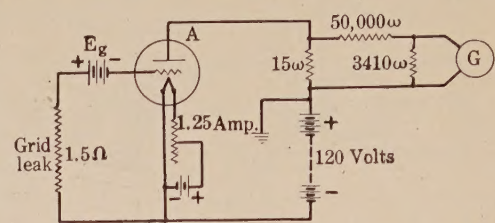


Fig. 14—Connection for Measurements of Characteristic Curves of the Electron Tube

is required for the amplification of the corona discharge current. (See Fig. 15). In these experiments, owing to its high sensitivity the galvanometer was equipped with a shunt, as shown.

From the curve of Fig. 15 it is seen that the grid voltage must be about 8 volts in order to secure zero deflection in the connection of Fig. 15. With the start of corona and current over the resistance *G*, we may

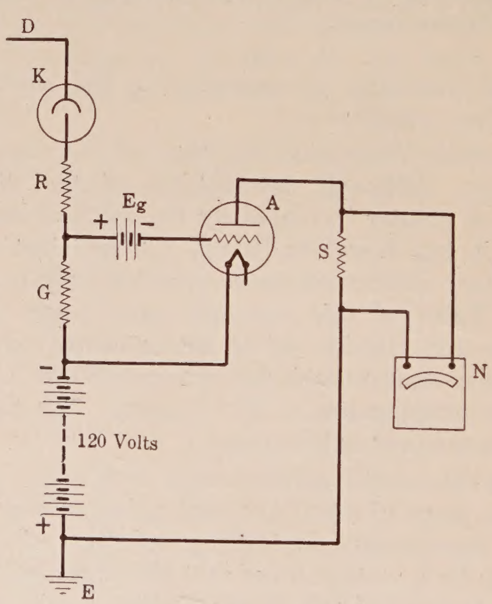


Fig. 15—Connection for Amplification of the Corona Discharge Current

expect a sharp increase in plate current, that is to say, amplification.

b. Connection and Operation of the Amplifier for Increasing Corona Discharge Current. The connections for amplification of corona discharge current are shown in Fig. 15; where *D* is the electrode in the corona voltmeter; *K* the rectifying valve already described, with plate connected to electrode *D*; *R*, protective resistance of 50,000 ohms; *G*, grid leak of 1.5 megohms; E_g, grid voltage (series of small cells); *A*, electrode tube

No. 102-A; S, shunt resistance for detecting instrument; N, Siemens and Halske portable needle galvanometer; E, ground connection and positive side of plate battery.

It is desirable that the needle of the galvanometer stand at zero position before the starting of corona discharge and that we have as large a deflection as possible on the start of corona, that is, we should have the same or better accuracy than is possible in using the d'Arsonval galvanometer without amplification or discharge. We were able to obtain this condition very closely after many trials by changing the value of the shunt resistance R and the value of the grid voltage E_g. We were able to obtain such conditions that the initial deflection of the galvanometer was less than one millimeter before the starting of corona, and immediately off the scale when corona begins. The process of obtaining this condition is clearly seen in Table II, where the relations between the shunt resistance, values of grid voltage, and initial deflection are given. The value of the grid leak was also varied from 50,000 ohms to 2 megohms, and it was found that 1.5 megohms grid leak gives most satisfactory results in amplification.

TABLE II.

Relations between the Grid Voltage and the Shunt Resistance of the Galvanometer.

Grid Voltage,	0.0	1.48	2.97	4.47	5.94	5.94	7.43	7.43	8.85	8.85
Shunt Resist. in ohms,	1.0	1.0	1.0	1.0	1.0	10.	10.	100.	100.	1000.
Tertiary Coil Volts,	Deflections in mm.									
22.0	7.8	7.7	5.5	2.0	0.8	5.0	1.0	2.8	0.5	0.7
38.1	7.8	7.7	5.5	2.0	0.8	5.0	1.0	3.2	0.5	0.7
38.2	No change	No change	No change	2.8	2.0	18.7	10.5	Off scale	24.5	Off scale
38.5				2.9	2.2	20.7	12.8		Off scale	
39.0				3.0	2.4	23.0	14.0			
39.5				3.1	2.6	Off scale	16.8			
40.0				3.2	2.7		20.0			

*Full scale of the instrument used was 25 mm.

In the above in all cases the galvanometer shunt resistance was made as high as possible. Higher values than those given result in large deflections at voltages below that of the start of corona. Corona at 38.2 volts on tertiary coil.

From the above results the following are the best values for amplification: Grid voltage, 8 to 9 volts; shunt resistance, 100 to 1000 ohms; grid leak, 1.5 to 2 megohms. Obviously the value of shunt resistance pertains only to the instrument used in these experiments, but the values of grid voltage and grid leak are always suitable for the type of tube described.

The importance of the rectifying valve for amplification should be emphasized. If no valve is used, alternating voltage is applied to the grid of the electron tube and will be so amplified that it will be impossible to secure zero deflection of the detecting instrument before the start of corona.

V. Further Study of Wave Form of Corona Discharge

A further study of the wave form of corona discharge has been made and in this the value of the discharge current has been carried far above that in the immediate neighborhood of the starting of corona.

a. Improvement of Synchronous Commutator. As shown in Fig. 5, the width of each slot filled with hard rubber corresponds to 20.2 electric degrees. If the middle brush, under which the open circuit is given by each slot, has no thickness, then the duration of open circuit must correspond to the interval of 20.2 electrical degrees and the deflection of the galvanometer is proportional to the mean value of the wave form during that interval. But obviously it has a certain contact area which will shorten the duration of open circuit, and the amount of this shortened period must correspond to the width of the brush contact area.

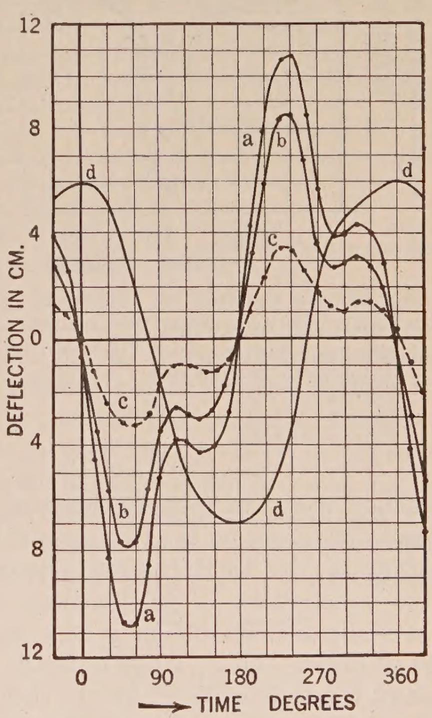


Fig. 16—Charging Currents at 36.5 Volts
(Corona starts at 37.2 volts)
Curve a—Charging current of electrode and lead wire together,
Curve b—Charging current of lead wire alone,
Curve c—Difference of curves (a) and (b),
Curve d—Wave form of voltage.

In the case of the observation of the curves shown in Figs. 6 and 11, two 0.005-in. copper strips were used as the middle brush. The effect of the wearing of contact surface and different pressures on the brush was noted in the difference of deflections in two measurements of wave form of the same current. As a consequence we used one sheet of 0.016-in. thickness because it is easier to keep the same wearing surface and the same pressure of contact with one thickness. After sufficient wearing the width of contact area was measured as about 1/32-in. This contact width of brush makes

the duration of open circuit about 16 electrical degrees, and the point on the wave form obtained by shifting this brush corresponds to the mean value of the wave form of width of 16 electrical degrees, thus the wave form as obtained by us is not an exact representation of corona discharge current, but is approximate only, each point on the curves representing a width of about 4.5 per cent of the entire period. With this commutator Figs. 16 to 19 were taken.

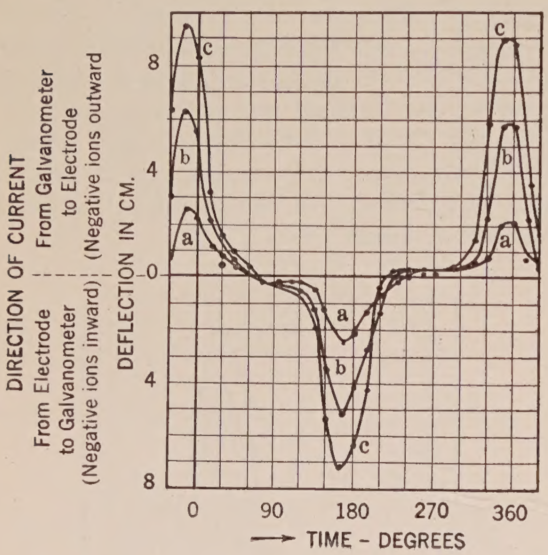


Fig. 17—No Voltage on Electrode

Corona starts at 36.7 volts,
Atm. press. 75.77 cm.
Temperature, 20.8 deg. cent.
Curve *a*—37 volts,
Curve *b*—41 volts,
Curve *c*—45 volts.

b. Galvanometer used. In order to obtain rapid readings of the two deflections on the two sides of zero, for the elimination of the thermoelectric electromotive forces on the commutator, a galvanometer of short period was used, sensitivity 1085 megohms undamped, and a period of 13.8 seconds. When critically damped with 1900 ohms the time required for the deflection to fall to zero from 12 cm. was 13.6 seconds.

c. Shielding of Lead Wire between Electrode D and the Galvanometer. Careful electrostatic screening of all connections and instruments is necessary in measurements of the small values of current in the connection to electrode *D*. At first electrostatic induction between the high-tension conductor of the voltmeter and the lead wire from the electrode to the screened observation room was found to be comparatively large. Working below the starting voltage of corona we measured the charging currents, (a) of electrode inside and lead wire outside together, and (b) lead wire alone by disconnecting at the outlet of the corona voltmeter. The wave forms in these two cases are shown in (a) and (b) of Fig. 16 respectively. The difference between these two curves is the charging current of the electrode itself. All have the same typical form, and the wave form of voltage is also shown in curve (d).

After completely shielding the lead wire by enclosing in metal tube, the charging current for both electrode *D* and lead wire when connected together is practically coincident with the curve (c) of Fig. 16, showing the elimination of exterior electrostatic induction.

It is not possible to eliminate completely the charging current of the electrode *D*, owing to the holes in the grounded cylinder of the voltmeter. These holes are essential to its principle of operation. Thus the wave form at voltage just above the start of corona is the superposition of the electrode charging current and the corona discharge.

d. Wave Forms of Corona Discharge Current with 0.289-*Cm. Nickel Steel Rod.* With the speed of the alternator maintained constant by a tuning-fork speed-control device and by shifting the commutator brush in the direction of rotation of the alternator, wave forms were taken for various conditions of corona discharge. Twelve points were taken on each half wave. We record three sets of wave forms as follows: (1) For no continuous potential between electrode and ground, (2) for negative electrode, and (3) for positive electrode. Each set consists of three curves, one taken just above the corona starting voltage, and two at values considerably higher. They are shown in Figs. 16 to 19.

It was possible to take only one set of curves in any one day and consequently different values of starting voltages of corona are shown. The charging current of the electrode for a voltage just below the starting of corona was taken in each case. The fact that the values of this charging current were equal in all three

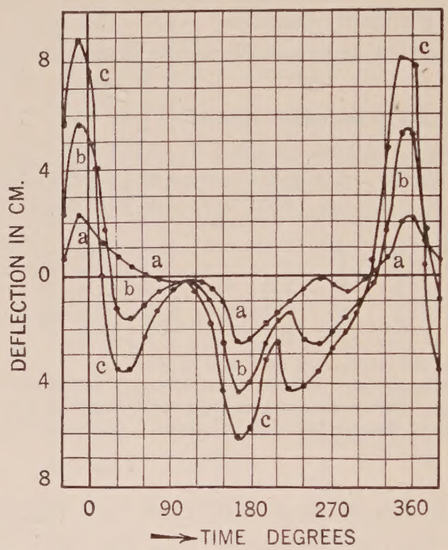


Fig. 18—Negative Electrode

Corona starts at 36.5 volts.
Atm. press. 75.47 cm.
Temperature, 25.2 deg. cent.
Direction of current:—same as Fig. 17.
Curve *a*—37 volts,
Curve *b*—41 volts,
Curve *c*—45 volts.

cases is a check on the satisfactory condition of the commutator and brushes.

In all of the curves (Figs. 16 to 19) 0 deg. and 180 deg. of electrical angle on the commutator scale were fixed by the position of zero charging current, corresponding to the maximum points on the voltage wave. The wave form of the voltage of the high-tension side of the transformer was measured by means of an air condenser, and is shown in Fig. 16. As the true wave form of corona discharge measured by the present method is the difference of the two wave forms below and above the critical value of voltage, it appears to be quite accurate only for voltage a small value above the corona starting value. For higher voltages, however, it is not correct to take the difference between, the total current and the charging current as measured since the charging current itself becomes larger. This

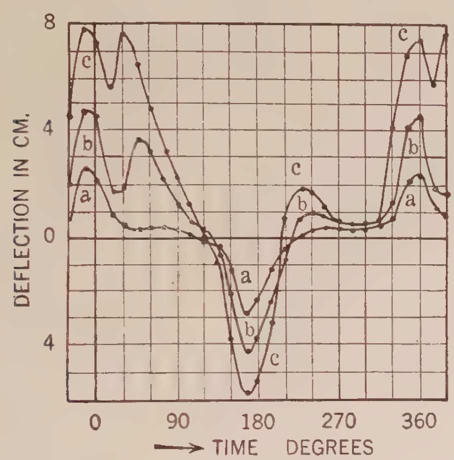


Fig. 19—Positive Electrode

Corona starts at 37.7 volts.
Atm. press. 76.86 cm.
Temperature, 21.2 deg. cent.
Direction of current:—same as Fig. 17.
Curve *a*—38 volts,
Curve *b*—41 volts,
Curve *c*—45 volts.

charging current is approximately proportional to the voltage except insofar as the capacity of the voltmeter may alter, due to the presence of corona. In the absence of definite knowledge on the magnitude of this alteration of capacity, the curves in Figs. 17, 18 and 19 were based on corrected values of the charging current for each voltage, assuming this charging current to be proportional to the voltage. All that may be said on this point at this time is that the shapes of the resulting curves indicate that a possible error on this account does not manifest itself in any serious change in the shapes of the curves. In Fig. 20, three curves are shown giving the net discharge currents under the conditions of Fig. 1. These curves are comparable with those of Fig. 2, except that they are taken with the d'Arsonval galvanometer used in the wave form experiments. The current read in these curves therefore is the algebraic sum of the positive and negative half waves of the discharge current. It is interesting to compare these curves with the wave forms of the currents under the corresponding conditions as shown in Figs. 17, 18 and 19. The deflection of the galvanometer in Fig. 20 without the use of commutator is proportional to the difference of the mean values of each half wave, and in the case of no potential on the electrode (Fig. 17) there is a slight difference between the two half waves, and this accounts for the relatively small deflection of the curve (*c*) in Fig. 20. In the

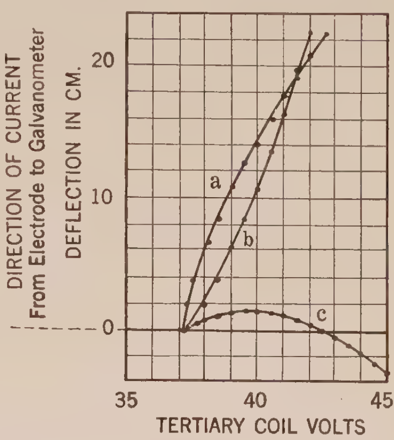


Fig. 20—Deflections of Galvanometer

Atm. press. 76.86 cm.
Temperature 21.2 deg. cent.
Curve *a*—Negative electrode,
Curve *b*—Positive electrode, (Reverse direction)
Curve *c*—No potential.

case of negative electrode (Fig. 18) the predominating mean value of half wave can be seen clearly as that whose direction is from the electrode to the galvanometer. A similar predominating mean value with direction reversed can be seen as pertaining to the curve (*b*) of Fig. 20, and the curves of Fig. 19.

We can offer no explanation of the very irregular shapes of the waves of discharge current when negative and positive potentials are used on the electrode. It

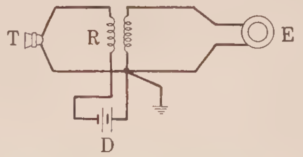


Fig. 21—Straight Telephone Circuit as Detector of Corona Formation

T—Telephone transmitter
R—Telephone repeating coil
D—Two dry batteries in series
E—Ordinal telephone receiver.

is noticeable that one-half wave in each case has the characteristic single peaked form as given by Fig. 17. It is the reverse wave which has the broken shape. We can only point to the complicated condition of ionization between the rod and outer cylinders, as influenced by the varying time above ionizing voltage, the rate of recombination of the ions, and the varying potential gradient. It is noticeable however that in the case of no potential on the electrode only one peak

was found for each half cycle of alternating current and this peak corresponds to the maximum point of voltage wave.

VI. Loud-Speaking Telephone for Corona Detection

As already mentioned, the telephone is an excellent detector of corona formation under laboratory conditions. The sound of corona transmitted by the ordinary transmitter and receiver is however rather too weak for use in the presence of other noises. The connections using an ordinary transmitter, repeater, and receiver for use as detection are shown in Fig. 21. In order to obviate the disadvantage mentioned we have tried a loud-speaking telephone and have succeeded in greatly amplifying the sound of corona discharge. Many experiments and different types of connection were tried before a substantial amplification was obtained, but for brevity we give only the results and final method of connection. The greatest difficulty was found in separating the pure corona note from other noises which were also picked up and amplified in the loud speaker. The connections of Fig. 22 g ivea very satisfactory amplification, so that observations on the beginning of corona are readily possible at some distance from the loud speaker and in the presence of normal noises of a large laboratory, such as the operation of several other machines and the talking of individuals. One stage of amplification with a Weston 102-A tube was used, and other details are given in connection with Fig. 22.

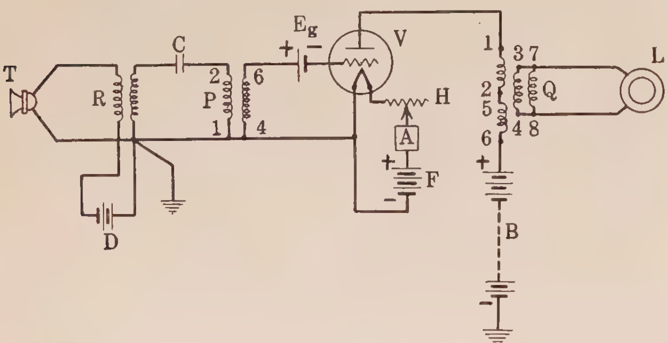


Fig. 22—Amplifier of the Sound of Corona Formation

D—Two dry batteries in series,
T—Telephone transmitter,
R—Ordinal telephone repeating coil,
C—Two condensers 2 μ. f. each in parallel,
P—Input transformer,
E_g—Grid voltage (1.5 volts),
V—Vacuum tube,
H—Wire resistance,
F—Filament battery (filament current:—about 1 ampere),
A—d-c. ammeter,
B—Plate battery 115 volts,
Q—Output transformer,
L—Loud-speaking telephone receiver.

While the results with the loud speaker are interesting, assuring the possibility of detecting corona formation and announcing it to several people at a distance, we believe that quite the same degree of accuracy of determination, if not better, can be obtained by a close-fitting head-piece, shutting out other noises, equipped with the ordinary telephone receiver. Under these circumstances extremely accurate indications of thé first appearance of corona are possible.

Detailed description of the rectifying valves, speed-control device, commutators, and other equipment mentioned in this paper will be found in a paper entitled "The Corona Voltmeter, the Electric Strength of Air," by J. B. Whitehead and T. Isshiki, A. I. E. E. Transactions 39, May 1920.

NOTES FROM THE BUREAU OF STANDARDS

CHARACTERISTIC SOFT X-RAYS FROM ARCS IN GAS VAPOR

Experiments have been conducted in which soft x-rays having wave lengths longer than those previously known were produced and their wave lengths determined. These x-rays differ in many ways from x-rays as probably understood. Thus, the x-rays which were first discovered were remarkable for their ability to pass through solid bodies which were opaque to ordinary light. All known substances, including even ordinary air, are, however, opaque to these soft x-rays which can only be detected by their effect upon objects located inside of the vacuum tubes in which the rays are produced. All of the chemical elements can be made under proper conditions to give off radiations which are characteristic of the element. Some of these radiations are visible light, and some are in the range of x-rays. The radiations here described are the softest, longest wave length x-rays characteristic of several of the elements.

Measurements have been made in 12 different gases and vapors. These experiments are of interest because they partially close the gap between visible light of the shortest and x-rays of the longest wave lengths previously made. It has been known for a long time that radio waves and light waves are both electromagnetic waves differing only in wave length, and about 10 years ago x-rays were found to be very short waves of the same kind. The radio waves ordinarily used are measured in meters and there is only a very small gap between the shortest radio wave and the longest heat waves; the latter have a wave length of about 0.3 mm. From the longest heat waves down to ordinary light waves, which have a wave length of a few ten-thousandths of a millimeter, there is no gap, and, indeed, measurements in the ultra-violet have been extended down to wave lengths only a little longer than 0.00001 mm. There was, however, a gap between this and the longest known x-rays which were a little more than 0.000001 mm. in wave length. The present measurements nearly close this gap as some of the x-rays measured are of greater wave lengths than are the shortest ultra-violet radiations.

The Use of Superimposed Imaginary E. M. Fs. Currents, and Fluxes in the Solution of Alternating-Current Problems

BY VLADIMIR KARAPETOFF
Fellow A. I. E. E.
Professor of Electrical Engineering, Cornell University.

Review of the Subject.—*The solution of some advanced problems on alternating currents leads to rather complicated trigonometric transformations. Let now, in addition to the real sinusoidal currents and voltages, certain imaginary currents and voltages be assumed to exist in the same circuit. These imaginary quantities may be selected of such a magnitude and phase that together with the real quantities they will give simpler mathematical expressions than the real quantities alone. In the final results the real and the imaginary terms can be readily separated, because an imaginary voltage cannot produce a real current, and vice versa.*

This method is based on some remarkably simple properties of certain mathematical functions which contain a real and an imaginary term, as compared to the properties of similar functions containing real variables only.

The following two analogs may make this method clearer.

A. In order to make extremely fine platinum wire, a piece of heavier platinum wire is coated with silver and then passed successively through several dies until it is reduced to the smallest practicable size. Then the tubular coating of silver is dissolved in nitric acid. It would not be possible to draw platinum alone to the same size. Here the use of silver is analogous to that of imaginary quantities in alternating currents. Silver is carried along in the operations and separated in the end.

B. In the manufacture of common ether, sulphuric acid is combined with alcohol and carried through certain operations. In the end this sulphuric acid is separated and used over and over again. Sulphuric acid in this case may be likened to imaginary currents and voltages which are added to real quantities at the beginning of the problem and separated in the end.

The immediate occasion for the writing of this article was a paper by Mr. Gilman referred to under (2) in the article. Had Mr. Gilman used superimposed imaginary currents, several pages of tedious mathematical transformations could be saved.

A more general reason for writing this article was a desire to bring this method to the attention of American engineers. It is hardly mentioned in American text-books, while it is quite well-known in England and on the Continent of Europe. As is stated in the introductory paragraph to the article, the method is not new, and the examples quoted are too self-evident to claim any originality. A brief introduction to the method will be found in the author's "Electric Circuit," p. 97.

The importance of the method lies in the possibility of solving certain electrical problems in a shorter and more direct way, and possibly in making the solution of certain problems feasible which in the ordinary way lead to too complicated expressions. It is a mathematical tool, and as such should find its place among other useful mathematical methods used in the solution of physical and engineering problems.

CONTENTS

Object of Paper

The object of the following remarks is to show the advantage of using exponential expressions of an imaginary variable in the solution of various problems involving alternating currents. While the method is not new, and has been used by writers like J. J. Thomson for a number of years, it does not seem to be sufficiently well-known to American electrical engineers, who continue to use more cumbersome methods involving long trigonometric expressions. In order to show the wide scope of application of this method, three entirely different problems are solved below, namely:

(1) To find the current in a circuit containing a resistance, a reactance and a capacity in series. The solution is based on the superposition of an imaginary e. m .f. upon the given terminal voltage.

(2) To find the distribution of eddy currents in a rectangular conductor in an armature slot. The problem is solved by superimposing imaginary eddy currents upon the real ones.

(2) To find an expression for a gliding m. m. f. or flux due to a symmetrical n-phase system. A simple expression is found by adding imaginary m. m. fs. to the real ones.

General Considerations

Let an alternating voltage $E \cos w\,t$ be applied to an electric circuit and produce in it certain currents and fluxes (magnetic or electrostatic, or both). The usual theoretical investigation of such a circuit, even without the transient part, is somewhat unwieldy because some terms in the equations contain $\sin w\,t$ while others contain $\cos w\,t$. We shall assume therefore that an addition to the real voltage, $E \cos w\,t$, an imaginary voltage $j\,E \sin w\,t$, acts upon the same circuits, where $j = \sqrt{-1}$. The total "complex" voltage is

$$e = E \cos w\,t + j\,E \sin w\,t = E \exp.\,j\,w\,t \qquad (1)$$

where

To be presented at the 10th Midwinter Convention of the A.I.E.E., New York, N. Y., February 15-17, 1922.

$$\exp. j\, w\, t = \epsilon^{jw} \qquad (2)^1$$

The real part of the voltage $E \exp. j\, w\, t$ reaches its positive maximum at the instants $w\, t = 0$, $w\, t = 2\,\pi$ etc. The real part of the voltage

$$e = \exp. j\, (w\, t + \gamma) \qquad (1a)$$

reaches its positive maximum at $w\, t = -\gamma$, that is, it leads the first voltage by the angle γ. In practical applications it is sometimes convenient to write the second voltage also in the form $E \exp. j\, w\, t$, only in this case E is no more a real quantity but a complex constan tof the form $E \exp. j\, \gamma$, where angle γ must be given separately. Thus if in equation (**1**), E is understood to be a complex quantity, then the equation represents a system of two equal sinusoidal voltages of the same frequency, a real and an imaginary one, in quadrature with one another. The exponential part of the factor E gives the angle by which this system of two voltages leads a reference system in which the real part reaches its maximum at $t = 0$.

This simplification is of extreme importance because in many cases it allows us to dispense with the longer notation (**1a**) and to use the shorter notation (**1**), no matter what the phase of an alternating quantity might be. The proper phase is included in the complex expression for the amplitude.

A complex voltage (1) produces in the circuit a complex current, the real voltage giving rise to a real current, and the imaginary voltage to an imaginary current. We thus can express the total complex current as

$$i = I \exp. j\, w\, t \qquad (3)$$

where, generally speaking, I is a complex quantity out of phase with the complex voltage E. Expressions (**1**) and (**3**), when used in the equations of a circuit, give simple relationships among its constants *because any derivative or integral of the exponential function, exp. j w t, with respect to t, is equal to the function itself multiplied by a certain constant, and thus the exponential factors drop out of the result.*

1. *A Circuit Containing Resistance r, Inductance L, and Capacity C in Series.* The well-known differential equation of state is

$$L \frac{d\, i}{d\, t} + r\, i + \frac{q}{C} = e \qquad (4)$$

where q is the condenser charge. Differentiating with respect to the time we get

$$L \frac{d^2\, i}{d\, t^2} + r \frac{d\, i}{d\, t} + \frac{i}{C} = \frac{d\, e}{d\, t} \qquad (5)$$

Substituting the values of e and i from equations (**1**) and (**3**) in equation (**5**), gives

$$L\, j^2\, w^2\, I \exp. j\, w\, t + r\, j\, w\, I \exp. j\, w\, t + (I/C) \exp. j\, w\, t = E\, j\, w \exp. j\, w\, t.$$

The factor $\exp. j\, w\, t$ may be canceled on both sides of the equation, and we get

$$I\, [-L\, w^2 + j\, r\, w + I/C] = E\, j\, w.$$

Multiplying both sides by $-j$ and dividing by w this expression is brought to the usual form

$$I\, [r + j\, (L\, w - 1/C\, w)] = E \qquad (6)$$

from which the well-known expressions for the impedance, z, and the phase displacement, ϕ, of the circuit may be derived. Namely, put

$$\left.\begin{aligned} r &= z \cos \phi \\ L\, w - \frac{1}{(Cw)} &= z \sin \phi. \end{aligned}\right\} \qquad (7)$$

Equation (**6**) then becomes

$$I\, z \exp. j\, \phi = E \qquad (8)$$

which means that numerically the voltage is equal to the current multiplied by z, and leads the current by the angle ϕ. The whole treatment does not involve the use of the expressions $\sin w\, t$ and $\cos w\, t$ at all.

2. *The non-uniform alternating-current density* Δ *in an embedded armature conductor of rectangular cross-section* is expressed by the partial differential equation

$$\tfrac{1}{2}\, w \frac{d^2\, \Delta}{d\, x^2} = \alpha^2 \frac{d\, \Delta}{d\, t} \qquad (9)$$

in which $w = 2\, \pi\, f$ has the same meaning as before, α is a physical constant, t is time and x is the distance from a reference plane. For a derivation of this expression see for example R. E. Gilman, "Eddy Currents in Armature Conductors," A. I. E. E. TRANSACTIONS, 1920. We are not concerned here with the proof of this equation but merely with its solution using imaginary currents. With a sinusoidal applied voltage, the current density in each layer $d\, x$ varies according to the sine law with the time, but is different in amplitude and in phase from layer to layer. Superimposing in each layer a quadrature imaginary current upon the real current, we may put the complex current density in the form

$$\Delta = u \exp. j\, w\, t \qquad (10)$$

where u is a complex function of x and takes into account the distribution of the current in the cross-section of the conductor. Substituting the value of Δ from equation (**10**) in equation (**9**) and cancelling the exponential term, we get

$$\frac{d^2\, u}{d\, x^2} = 2\, j\, \alpha^2\, u \qquad (11)$$

This differential equation does not contain time and is much simpler than the original equation (**9**). The well-known solution of equation (**11**) is

1. In this article the notation $\exp. j\, w\, t$ is used in place of the usual exponential notation, because the first form is better adapted to the modern mechanical typesetting. While the difference may not be of importance in a mathematical deduction in which exponential terms occur infrequently, it seems preferable to use the straight "lower case" notation in the following problems because the formulas are predominantly of the exponential type and the principal transformations occur in the exponents. We are used to the expression $\log x$ and there is no reason why the inverse function, $\exp. x$, should not be written without using superior letters.

$$u = P \exp. \beta x + Q \exp. (- \beta x) \qquad (12)$$

where P and Q are complex constants of integration, and

$$\beta = (1 + j) \alpha = \alpha \sqrt{2 j} \qquad (13)$$

Thus, the complex flux density is

$$\Delta = P \exp. (\beta x + j w t) + Q \exp. (- \beta x + j w t) \qquad (14)$$

Separating the real part of this expression from the imaginary, a formula is obtained for the true current density in the conductor, at any instant t and at any point corresponding to the distance x. A perusal of Mr. Gilman's article will readily show the advantage of the above method as compared with the use of long trigonometric expressions which lead to simultaneous equations.

3. *Polyphase Gliding Magnetomotive Force.* It is known to students of polyphase machinery that n *alternating* sinusoidal magnetomotive forces of amplitude M each, differing in time by $2 / \pi n$ from each other, and shifted in space by $2 \pi / n$, produce a uniformly *gliding* magnetomotive force of amplitude $\frac{1}{2} n M$. See, for example, E. Arnold, *Wechselstromtechnik*, Vol. III (1912), p. 241. The usual proof may be simplified by superimposing imaginary magnetomotive forces upon the real. To simplify the formulas further we select such a unit of time that one cycle of current takes place in 2π units of time. Then variations of a magnetomotive force with the time are expressed by the factor $\cos t$, because $w = 1$. Similarly we select such a unit of length that a complete wave of magnetomotive force occupies 2π units of length. The variations of the m. m. f. in space are then expressed by the factor $\cos x$. Thus, an instantaneous m. m. f. due to the first phase, at a point x and at an instant t is

$$m' = M \cos t \cos x \qquad (15)$$

We now superimpose upon this m. m. f. an imaginary m. m. f in time quadrature and in space coincidence with it, that is, one of the form $j M \sin t \cos x$. We then get the following *complex* wave:

$$m = M \cos x \exp. j t \qquad (16)$$

But according to a well-known formula of trigonometry of complex angles

$$\operatorname{Cos} x = \tfrac{1}{2} [\exp. j x + \exp. (- j x)] \qquad (17)$$

so that equation (16) becomes

$$m = \tfrac{1}{2} M [\exp. j (t + x) + \exp. j (t - x)] \qquad (18)$$

The factor $\cos (t + x)$ corresponds to a wave gliding synchronously towards decreasing values of x (say to the left), while $\cos (t - x)$ corresponds to a wave gliding towards increasing values of x (to the right). See for example the author's "Magnetic Circuit," p. 126. Thus we obtain the well-known result that a pulsating m. m. f. or flux of amplitude M may be resolved into two oppositely gliding m. m. fs. or fluxes, each of amplitude $\frac{1}{2} M$.

We now shall consider the real m. m. f. in each phase as being supplemented by a quadrature imaginary m. m. f. wave, and the resulting complex pulsating wave resolved into two oppositely gliding waves, as before. By analogy with equation (18), the expressions for these waves will be as follows:

$$\left.\begin{aligned}
m_1 &= \tfrac{1}{2} M \exp. j (t + O + x + O) \\
&\qquad + \tfrac{1}{2} M \exp. j (t + O) - (t + O) \\
m_2 &= \tfrac{1}{2} M \exp. j(t + \delta + x + \delta) \\
&\qquad + \tfrac{1}{2} M \exp. j [(t + \delta) - (x + \delta)] \\
m_3 &= \tfrac{1}{2} M \exp. j (t + 2 \delta + x + 2 \delta) \\
&\qquad + \tfrac{1}{2} M \exp. j [(t + 2 \delta) - (x + 2 \delta)] \\
&\text{etc.} \qquad\qquad \text{etc.}
\end{aligned}\right\} \qquad (19)$$

In these expressions the angle δ represents both the time and space displacement between two adjacent phases, that is,

$$\delta = 2 \pi / n \qquad (20)$$

To find the resultant m. m. f. due to all the n phases, we have to form the sum of $m_1 + m_2 + m_3 +$ etc. It will be readily seen that δ disappears in all the second terms on the right-hand side of the equations (19). All these terms are equal to each other and their sum is equal to $\frac{1}{2} n M \exp. j (t - x)$. The sum of the first terms on the right hand side is equal to zero because

$$1 + \exp. j 2 \delta + \exp. j 4 \delta + \text{etc.} = 0 \qquad (21)$$

In order to see this, think of 1 in equation (21) as representing a unit vector. Then $\exp. j 2 \delta = \cos 2 \delta + j \sin 2 \delta$ represents a unit vector turned with respect to the first one by the angle 2δ. See the author's "Electric Circuit," p. 94. Similarly the term $\exp. j 4 \delta$ represents a unit vector at an angle 4δ with the first, or forming the angle 2δ with the second, etc. Thus, equation (21) represents a geometric addition of n unit vectors, each turned with respect to the preceding one by the same angle $2 \delta = 4 \pi / n$. Graphically such a sum corresponds to a regular closed polygon, that is, the sum of the vectors is equal to zero, whether n is an odd or even number.

Having proved equation (21) we apply it to the sum of the first terms on the right hand side of equations (19) by factoring out $\frac{1}{2} M \exp. (t + x)$, and thus show that the result is equal to zero. Consequently, the whole polyphase m. m. f. is due to the second terms and we may write:

$$\text{total complex m. m. f.} = \tfrac{1}{2} n M \exp. j (t - x) \qquad (22)$$

The imaginary part may now be dropped, and we obtain the following final result:

$$\text{total real m. m. f.} = \tfrac{1}{2} n M \cos (t - x) \qquad (23)$$

The resultant m. m. f. in this case is gliding to the right because the exciting currents have been assumed to lag in the consecutive phases from left to right. With an opposite assumption the resultant m. m. f. would glide to the left.

Prevention of Transient Voltage in Windings

BY J. MURRAY WEED
Member A. I. E. E.
Power and Mining Engineering Department, General Electric Company, Schenectady, N. Y.

***Review of the Subject.**—This paper relates to windings such as are used in transformers, reactors and the like, with particular reference to the characteristics which determine internal distributions of suddenly impressed voltages or sudden voltage changes, and the resulting internal oscillations. Ordinary lightning arresters, which limit the maximum voltages reaching the winding terminals, but cause rather than prevent the occurrence of sudden voltage changes, certainly give no protection against excessive voltages between turns or between coils. After describing the production of these transient voltages in ordinary windings, and pointing out that the treatment of symptoms by the addition of extra insulation tends to defeat itself by augmenting the cause, this paper explains these phenomena as due to faulty arrangements of inherent capacitance with the inductance of the winding. A fundamental principle is evolved indicating the constitutional remedy, which, if perfectly applied, would give only uniform internal voltage distributions, however abrupt or frequent the voltage changes at the terminals might be. Methods of application are described for the ordinary windings, by supplementing the faulty arrangements of inherent capacitance with auxiliary capacitances or condensers. Methods are given, also, for the construction of windings with the ideal distribution of inherent capacitance called for by the principle.*

Two alternative statements of the fundamental principle upon which the ideal distribution of capacitance is based are emphasized in the paper, and the application of the principle is adequately illustrated in the figures, of which Fig. 2 is a simplified diagrammatic representation of the arrangement of inherent capacitance with the inductance of that certain type of ordinary windings shown in Fig. 1, Figs. 3 to 5 illustrate methods of correcting this faulty arrangement by means of supplementary condensers, Figs. 6 and 7 show two typical forms of a general method of constructing windings with the ideal distribution of inherent capacitance, and the remaining figures illustrate practical modifications of this method.

With the ideal distribution of capacitance with inductance called for by the fundamental principle here enunciated, sudden and erratic changes in voltage at the terminals of the winding, or impressed wave trains of any frequency, result only in voltage distributions which are at every instant uniform. With practical arrangements approximating the ideal one, it is only necessary to insulate between turns and between coils, with ordinary factors of safety, for the proportional part of the maximum voltage which may appear at the terminals.

CONTENTS

How Transient Voltages Are Set Up in Ordinary Windings

In ordinary electrical windings, in which all of the turns link a common magnetic circuit, such as those for alternating current transformers or reactances, any fluctuating or alternating voltage existing across or in the windings, unless the fluctuations or changes within the cycle are very rapid, has at each instant of time a practically uniform distribution throughout the winding. Voltages between points in the winding at any instance are approximately proportional to the numbers of intervening turns. Practically uniform voltage distribution thus prevails throughout such windings in normal steady operation at ordinary commercial frequencies. On the other hand, the resulting voltage distribution at the instant of a sudden voltage change, as from the closing of a switch, is far from uniform, and results in an internal oscillation. Moreover, voltage distributions and oscillations due to successive sudden voltage changes will superpose, augmenting each other if in synchronism and in phase, but tending to neutralize each other if in phase opposition. The internal voltages resulting in this manner from a succession of sudden voltage changes thus depend upon the way the changes are timed with respect to each other. Similar results will be produced, if the voltage changes at the terminals are sufficiently rapid, even though they are not absolutely instantaneous. With an external oscillation or high-frequency wave train arriving at the terminals, if the frequency is the same as the frequency of the internal oscillations, internal resonance will occur, and excessive voltages may be produced between neighboring portions of the winding. A single large sudden or quick change of voltage at the terminals of a winding may, in fact, produce transient voltages between turns which are very large as compared with those corresponding to uniform distribution, and the insulation stresses resulting from a succession of voltage impulses or a high-frequency wave train may become relatively much higher than those due to a single impulse.

To be presented at the 10th Midwinter Convention of the A. I. E. E., New York, N. Y., February 15-17, 1922.

Extra Insulation Constitutes Treatment of Symptoms

Occurrences of the phenomena described above have demonstrated themselves in practise through years of painful experience, in the rupture of insulation between turns and between coils, resulting from switching, arcing grounds and lightning. As demands for reliability increased, and experience seemed to show the need of it, the insulation was increased, until its effect upon the cost and characteristics of transformers became a serious handicap. An unfortunate and for a long time mysterious phase of the situation lay in the fact that each increment in the insulation provided seemed to be followed, and as we can now understand, actually was followed, by a corresponding increment in the transient voltages which might appear to break it down. (From what follows, this will be seen to be due to the reduction of capacitance between turns caused by the increased thickness of the intervening spaces occupied by the insulation.)

Object of the Paper

While it has long been known that these results were due to capacitance within the winding, it is obviously impossible to eliminate capacitance, and the subject was not sufficiently well understood to avoid the evil effects. It is the object of this paper to enunciate a fundamental principle whereby the evil effects of capacitance in windings can be avoided, and to describe several practical methods for the application of this principle. The principle involved becomes obvious and will be stated after a brief review of the way capacitance occurs in windings and of how it affects voltage distribution.

Distribution of Capacitance

Every portion of the inductance of any winding, as represented by a turn or a coil, may be considered as having a certain amount of capacitance in parallel with it, as the capacitance between turns and the capacitance between coils. The conclusions which it is here desired to draw from these considerations will not be affected by the fact that these capacitances are distributed around the turns and through the coils. Capacitances or elements of capacitance are also found between the various parts of the winding and grounded parts of the apparatus or surrounding objects, which will be included under the general term of capacitance to ground.

Effect of Capacitance on Initial Distribution of Suddenly Impressed Voltages

Any voltage appearing suddenly at the terminals of such a combination of inductance and capacitance must be accompanied by an impulse of current necessary to charge the various elements of capacitance. The charge for each element is transmitted through other capacitance elements in series with it, since no current can flow through the inductance at the first instant. It is evident, therefore, that the voltage distribution at the first instant will be that due to the action of capacitance alone. In the ordinary winding, this distribution will be far from uniform with respect to the turns and coils of the winding, the instantaneous voltage across the end turns, for instance, being relatively very great.

Effect of Capacitance on Initial Distribution of Current Growth

The voltage across each individual turn, resulting from the initial distribution due to capacitance, constitutes the initial impressed voltage for that particular turn. This voltage must be opposed by an equal voltage magnetically induced in the turn. This induced voltage, however, is not merely that due to the self-inductance of the individual turn, but it is the summation of the voltage of self-inductance, which is due to the growth of current in this turn alone, and all the voltages of mutual inductance set up in this turn by the growths of current in other turns. The growth of current will be maximum in those turns for which the impressed voltage is maximum while in the turns of minimum impressed voltage the current growth may be minimum in the positive sense, or it may be in the negative sense with maximum negative value. A negative growth of current will occur in any turn in which the summation of voltage of mutual inductance due to current growths in other turns which is opposed to the impressed voltage for that turn is greater than this impressed voltage.

Production of Internal Oscillations

The natural tendency of this initial distribution of current growth, by redistributing the condenser charges, is toward a uniform distribution of the voltage. Unfortunately, however, as this condition is approached we find a nonuniform distribution of current. With perfect mutual inductance between all of the turns, the current would become uniform at the proper instant, and both current and voltage distribution would remain uniform, but on account of magnetic leakage between different parts of the winding, the current can be brought to uniformity only after a further redistribution of voltage, giving maximum voltages where minimum voltages were previously found, and vice versa.

Superposition of Oscillations

We have thus roughly outlined the first swing of an internal oscillation which will be gradually damped out, resulting in a condition of uniform voltage distribution provided there are no further quick voltage changes at the terminals. If a succession of such voltage changes appear, the voltage distribution and oscillations which would be caused by each change will be superposed upon the remaining effects of all previous changes.

Fundamental Principle on Which The Constitutional Remedy is Based

The fundamental principle whereby these non-uniform voltage distributions and oscillations may be eliminated from windings will now be stated as follows:

If the capacitance associated with any inductance is so disposed that the initial distribution of a suddenly impressed voltage, which is effected by the capacitance, is uniform with respect to the inductance, the growth of current within the inductance will be uniform, and the voltage distribution will therefore remain uniform, each element of capacitance receiving charge at the same rate that it loses it.

In a winding which meets these conditions, the current in all parts will be the same at each instant of time. The action within a given turn of the mutual inductances between it and the various other turns, in this case, will be exactly like and simultaneous with that of its own self-inductance. These mutual inductances are with propriety, therefore, all included with the strictly self-inductance of the turn as the inductance referred to in the statement of the principle, although it is necessary to distinguish between the self-inductance of the turn and mutual inductances between it and other turns in considering the effects of quick voltage changes when this principle is not complied with.

Perfect Cure Would Result from Exact Application

In a winding fully complying with this principle, the voltage distribution would be uniform at all times, without regard to the abruptness or frequency of voltage changes at its terminals. The voltage which could appear across the insulation between turns or between coils would be limited to a value proportioned to the voltage at the winding terminals by the ratio of the number of intervening turns with the total number of turns in the winding. To provide the insulation necessary for safety, therefore, it would be necessary to consider only the proportional part of the maximum voltage which can appear, or would be permitted to appear, across the total winding. Moreover, for the provision of suitable external protection, it would be necessary to limit only the maximum voltage the suddenness and frequency with which voltage changes occur being of no importance.

Approximate Methods Giving Practical Results

Several methods will now be described whereby a disposition of capacitance in accordance with this principle may be obtained with sufficient approximation for practical purposes, thus reducing the insulating of windings to a rational basis wherein the internal insulation required bears a definite relation to the normal operating voltage between the parts involved, as expressed by moderate factors of safety, and at the same time removing the necessity for restrictions as to switching, eliminating the danger from arcing grounds and simplifying the duties of lightning arresters.

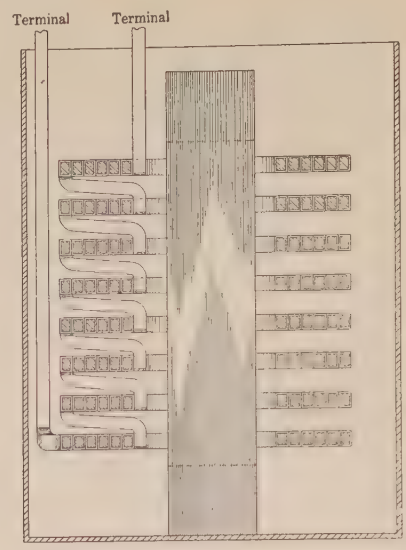


Fig. 1—Reactor Winding in Cross-Section—Case and Laminated Core Grounded

The reactor is chosen for illustration instead of a transformer on account of its more simple arrangement of inherent capacitance, which is shown diagrammatically in Fig. 2. The methods of correcting faulty arrangements of capacitance, illustrated in Figs. 3, 4 and 5 with reference to this winding, if correctly carried out, are applicable to the more complicated cases of transformers.

General Method Applicable to Ordinary Windings, Supplementing Inherent Capacitance

A general method suggests itself which is applicable to ordinary windings, by the provision of a system of supplementary capacitances or condensers, so proportioned and interconnected with the winding as to give the desired disposition of combined supplementary

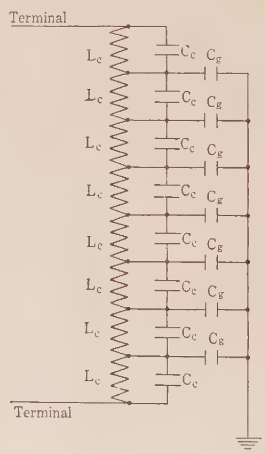


Fig. 2—Arrangement of Inherent Capacitance with Inductance in the Reactor of Fig. 1, Somewhat Simplified

Inductance elements L_c correspond to the individual coils, condenser elements C_c represent capacitances between coils and condenser elements C_g represent capacitances to grounded core and case. Without ground capacitance, the initial distribution of suddenly impressed voltages would be uniform. The ground capacitances cause greater initial voltages across coils which are nearer to the line terminals, resulting in subsequent oscillations.

and inherent capacitance. This is illustrated in connection with the very simple arrangement shown in Fig. 2, which is here chosen for simplicity of treat-

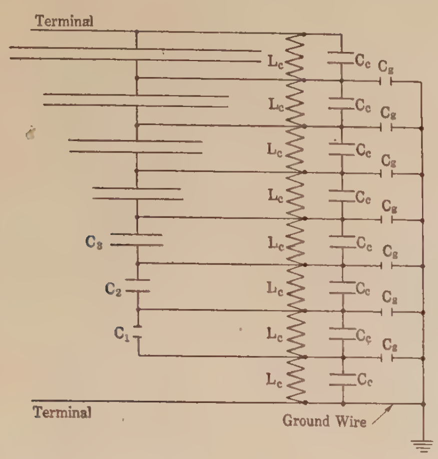


Fig. 3—A Method of Neutralizing Effects of Ground Capacitance in Arrangement Shown in Fig. 2

This method is applicable only when the winding is definitely grounded at some point. It consists in connecting condensers C_1, C_2, etc., across individual coils, the capacities of the respective condensers being given by the equation $C_n = \frac{n^2 + n}{2} C_g$, where n is the number of the supplementary condenser, counting from the point of grounding.

ment. This diagram represents a simplification of the disposition of inherent capacitance in the reactor winding of Fig. 1. The capacitances between coils appear as equal condenser elements, C_c, in parallel with the equal inductance elements, L_c, which represent the inductances of the individual coils. The condenser elements, C_g represent capacitances to ground or to neighboring conducting surfaces. If

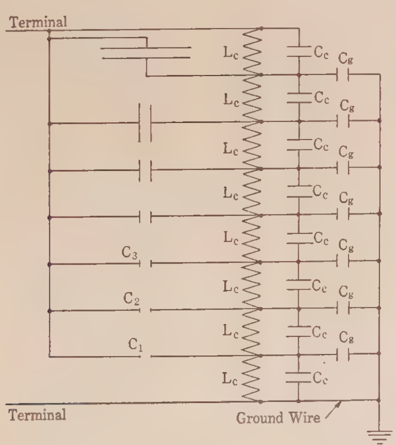


Fig. 4—A Method of Neutralizing Effects of Ground Capacitance Alternative to that Shown in Fig. 3, Applicable only when Winding is Grounded

Condensers C_1, C_2, etc., are connected between the line terminals and various points of connection between coils. The capacities of the respective condensers are given by the equation $C_n = \frac{n}{N-n} C_g$, where n is the number of the supplementary condenser, counting from the point of grounding, and N is the number of coils between this point and the line terminal.

the ground capacitances could be eliminated, and if the arrangement of inherent capacitance with inductance were adequately represented by the C_c and L_c elements of Fig. 2, this would constitute an ideal arrangement in which the initial distribution of a suddenly impressed voltage would be uniform. The ground capacitances result in a condition for the various coils with respect to the suddenly impressed voltage, with which we are familiar in connection with suspension insulators, where the maximum voltage appears across the disk at the line end of the string. In the winding, the initial voltages will be greater for coils which are nearer to the line terminal, and these initial voltage distributions result in oscillations, as described above, due to reactions between the inductance elements and the capacitance elements. Specific

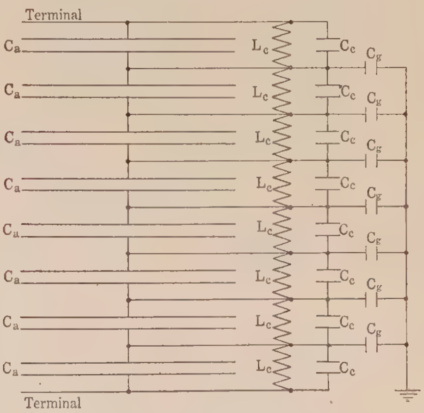


Fig. 5—A Method of Neutralizing Effects of Ground Capacitance in Arrangement Shown in Fig. 2, which does not Require Grounding

The condensers, C_a, connected across the individual coils, must be large as compared with the inherent ground capacitances or possible inequalities between intercoil capacitances. If the coil inductances are unequal, these condensers must be unequal, their capacitances being in inverse proportion with the inductances.

methods for correcting this faulty disposition of inherent capacitance by means of supplementary condensers, which, if correctly carried out, are applicable to the more complicated cases of transformers, will now be given.

Methods Limited to Grounded Winding

If the winding is definitely grounded at one end, we will be able to neutralize the effects of the C_g elements, by means of supplementary condenser elements, by either if the methods illustrated in Figs. 3 and 4. With all the capacitance elements C_g equal, the required capacitance of any supplementary condenser C_n, in Fig. 3, is

$$C_n = \frac{n^2 + n}{2} C_g$$

and the required capacitance in Fig. 4 is

$$C_n = \frac{n}{N - n} C_g,$$

where n is the number of the condenser, counting from the grounded end, and N is the total number of coils.

Method Without Ground Limitations

To carry out correctly the arrangements shown in Figs. 3 and 4 would require an indefinite number of sizes of auxiliary condenser units to fit the different cases and definite knowledge of the amounts and locations of the inherent capacitances of the winding. Moreover, they would possess the obvious disadvantage that they can be applied only in connection with a grounded winding. A method without these disadvantages is illustrated in Fig. 5, where the auxiliary condenser units, C_a, are all equal, and of sufficient size to overpower the inherent capacitances to ground. That is, the capacitance C_g is negligibly small in comparison with the capacitance of an auxiliary condenser unit. With this arrangement it makes no difference where the ground is located on the protected winding, or whether or not it is grounded at all.

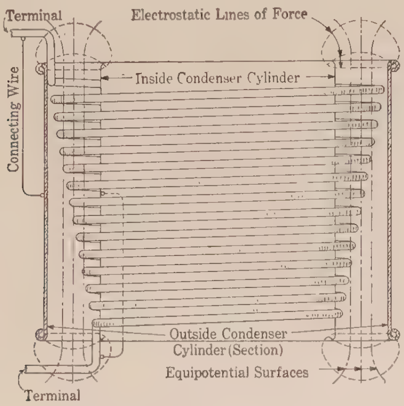


Fig. 6—Tapered Single-Layer Winding Embedded in Dielectric of a Condenser Consisting of Two Concentric Cylinders

The condensers plates (cylinders), are respectively connected to the winding terminals, and the winding progresses gradually, turn by turn, in the radial direction from one plate to the other, so that the electrostatic potential impressed upon each turn by the action of the condenser field corresponds to a uniform distribution of voltage. Nonuniform voltage distributions and internal oscillations cannot occur in windings so disposed.

More General Case and Alternative Statement of Fundamental Principle

The method illustrated in Fig. 5 has been described in connection with a winding in which the various inductance portions were assumed to be equal. It is clear, however, that the same general method is applicable to any winding in which leads for connection to condenser units are brought out at convenient intervals, breaking up the inductance into parts which may not be equal. In this case, the capacitances of the auxiliary condenser units must not be equal but must be proportioned in accordance with the fundamental principle given above. For this application the principle may be stated in a more convenient form, as follows:

To give uniform distribution, with respect to the inductance, of voltages appearing suddenly across the terminals of windings, the capacitances in parallel with all of the various portions of the inductance must be in inverse proportion with the respective portions of inductance.

Limitations of Supplemental Methods

The methods which have been described insure that the voltages which can appear across the various coils or portions into which the winding is divided by the condenser leads are proportional to the respective portions of inductance, the sum of these partial voltages at any instant being the total instantaneous voltage across the whole winding, but they do not insure uniform distributions within the individual coils or portions of the winding, since the way capacitance occurs within these portions has not been affected.

If the way the voltage appearing across any individual coil distributes itself throughout the coil were not affected it is evident that voltages which may appear between turns or across portions of the coil will be reduced in the same proportion as that across the whole coil. As a matter of fact the reduction in voltage between turns or across portions of the coil will be greater in proportion than that across the coil as a whole, and this proportional reduction will be more marked the larger the auxiliary capacitances which are used. This is on account of the relatively large amount of electricity required to charge the auxiliary condensers, and the limited current which can be supplied from the line. The change in voltage across the entire winding, and consequently, that across the individual coil, will be less rapid with the condensers than without them, and less non-uniformity of voltage distribution among the turns of the coil result naturally from the more gradual change across the coil as a whole.

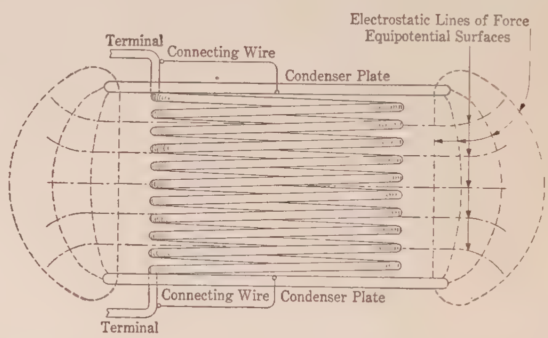


Fig. 7—Cylindrical Single-Layer Winding Embedded in Dielectric of a Condenser Consisting of Two Parallel Plates

The equivalent arrangements shown here and in Fig. 6 are typical forms of a general method for the construction of windings with the ideal distribution of inherent capacitance.

Method of Constructing Windings with Ideal Distribution of Inherent Capacitance

The methods which have thus far been described are applicable as a corrective measure in connection with ordinary windings of previous types. It is, how-

ever, possible to design and build windings in which the inherent capacitances will have the ideal distribution, so that no supplementary condensers will be needed. A general method which completely meets the conditions for uniform voltage distribution

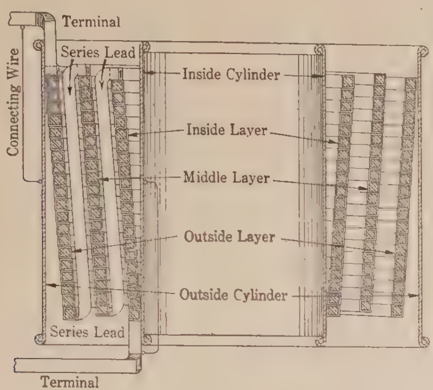


FIG. 8—MULTILAYER WINDING, IN CROSS-SECTION OF TYPE SHOWN IN FIG. 6

The last turn of one layer is connected to the first turn of the next layer by a series lead passing between the layers. Except for the disturbing effect of these leads, which constitutes a departure from ideal conditions, this arrangement gives the same results as a single layer of three times the length, progressing gradually from one cylindrical plate to the other. A slight modification of this arrangement would result from making the winding layers cylindrical and tapering the plates.

with respect to the individual turns, without the use of supplementary condensers, is illustrated in typical forms in Figs. 6 and 7. This method consists in enclosing or embedding the entire winding within the dielectric of a suitably proportioned condenser, the terminal plates of the condenser being connected to the terminals of the winding, and each turn of the winding being so positioned that, with uniform voltage distribution,

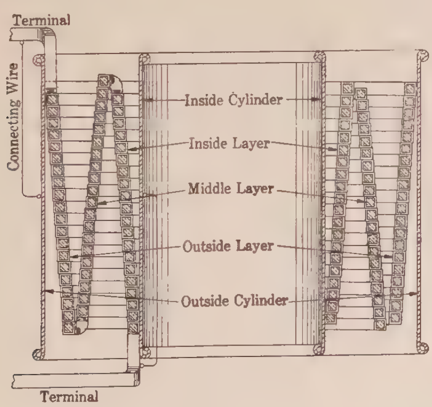


FIG. 9—ARRANGEMENT EQUIVALENT TO THAT SHOWN IN FIG. 8

The series leads between layers are eliminated by inverting the middle layer.

its potential will be the same as that which would exist in the part of the dielectric where the turn is located if the winding were not present. Turn by turn or element by element, the winding traverses the dielectric of the condenser, progressing gradually from one terminal plate toward the other. Modifications of these typical forms, embodying multilayer constructions, are shown in Figs. 8 and 11.

EFFECT OF WINDING CONDUCTOR THICKNESS

A matter to be noted in connection with these arrangements of windings between condenser plates is

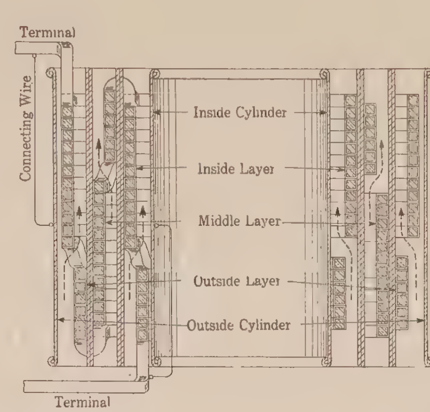


FIG. 10—MODIFICATION OF ARRANGEMENT SHOWN IN FIG. 9

Cylindrical layers or sections of layers are substituted for the tapered layers. With the mid turn of each layer section in its correct position with respect to the condenser plates, corresponding to Fig. 9, it is seen that the other turns are slightly displaced from their ideal positions. This arrangement permits the introduction between layers of insulating cylinders and of passages for the circulation of cooling fluid. These passages are offset as indicated by the curved arrows.

found in the fact that the winding conductor occupies space which otherwise would be occupied by the dielectric of the condenser. If this conductor possessed only length and breadth, lying within equipotential

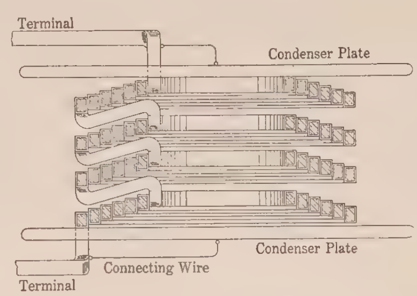


FIG. 11—MULTICOIL WINDING OF TYPE SIMILAR TO THAT SHOWN IN FIG. 7, THE COILS BEING CONICAL IN SHAPE INSTEAD OF CYLINDRICAL

The arrangement of this winding with respect to the disk-shaped condenser is similar to that of Fig. 8 with respect to the cylindrical condenser A slight modification of this arrangement would result from making the coils flat and the condenser plates concial. Other practical modifications of this arrangement, similar to those shown in Figs. 9 and 10 for the arrangement of Fig. 8, are obvious.

surfaces, no effect would be felt, but due to its thickness in the direction of the field, it eliminates or short-circuits all potential drops within the space occupied. So far as the dielectric is concerned the effective distance between the plates is thus reduced by the combined thickness of the intervening conductors. In fixing the relative distances of the various turns from the respective plates, the thickness of intervening

conductors should be neglected, measuring only those portions of distance which are within the dielectric, and, of course, measuring in each case to the adjacent surface of the turn, and not to the center of its section.

Practical Modifications and Approximate Methods

As in the case of all engineering applications, practical considerations must here be taken into account. With the arrangement shown in Fig. 8, we find a disturbing element in the leads passing between the layers for connecting adjacent layers in series. These leads locally reduce the effective distance through the dielectric between layers, thus introducing extra voltage stresses. This becomes important when the normal layer voltages are high. If this were the only matter to be considered, this disturbing element might be escaped by inverting intermediate layers, giving the arrangement illustrated in Fig. 9. This would be a theoretically good arrangement, but one which may be modified further with several important practical advantages, making the arrangement only a little less good from the standpoint of voltage distribution. Thus, in the arrangement shown in Fig. 10, cylindrical insulating barriers have been introduced between adjacent layers, ducts have been opened up for the free circulation of cooling fluid, and the winding layers have become cylindrical instead of tapered. The middle point of each cylindrical layer portion of the winding occupies its ideal position in the dielectric, while turns on opposite sides of each mid-turn make slight departures from their ideal positions in opposite directions, the departure increasing gradually as we pass further from the mid-turn. This will permit corresponding departures from uniform initial distributions of suddenly impressed voltages within the individual layer sections, although the distribution of the total terminal voltage among the different sections will be in proportion with the numbers of turns between respective mid-turns.

CORRESPONDENCE

PHYSICAL CONCEPTION OF INDUCTION MOTOR OPERATION

To the Editor:

In his article on page 851 of the JOURNAL for November, 1921, Mr. J. Lebovici makes a plea for the abandonment of what he calls the "indirect" method of explaining the action of the single-phase induction motor. He considers that this indirect method—by which the single-phase stator winding is regarded as equivalent to a pair of superimposed polyphase windings producing a pair of oppositely rotating fields of equal angular velocity—ought to be abandoned in the interests both of clearness of conception and of "economy of thought," just as, for such reasons the description of heat phenomena in terms of a heat substance has been abandoned.

Economy of thought and clearness of conception are important objects and they often are attained by the abandonment of superfluous hypotheses. The abandonment of the unnecessary and actually unwarranted hypothesis of a heat substance is a good case in point, but I question very much whether there is in any sense a comparable case to be made out for the abandonment of the so-called indirect method of treatment of the single-phase induction motor. This method involves no unnecessary, much less any unwarranted hypothesis, nor can it appropriately be called indirect.

Mr. Lebovici gives an instance in which false reasoning as applied to this method gives false results, but I fail to see what bearing this has upon the virtues or short-comings of the method.

The term "indirect" suggests that the single-phase stator may be regarded only in an indirect sense as setting up a pair of rotating fields. As a matter of fact the two oppositely rotating fields do indeed exist. There is no mere hypothesis about this; it is an actual physical fact, and no method which fails to take this fact fully into account can be complete. The magnetomotive force due to a single-phase stator winding is identical with that produced by a pair of polyphase windings wired to produce a pair of oppositely rotating fields. This fact hardly calls for demonstration but it may be demonstrated very readily by aid of a dot and cross diagram applied to a two-pole stator having a pair of two-phase windings superimposed. Both phases of the combined winding thus formed carry the same resultant current, namely the vector sum of the currents in the individual phases I and II, so that all the coils of both windings might just as well be put in series and supplied with single-phase current; that is to say, the pair of two-phase systems each producing its own rotating field is identical with one combined single-phase winding.

Sight ought not to be lost of the fact that every form of induction motor—the single-phase no less than the polyphase form—depends for its action directly upon a revolving field. Any method of treatment worthy to be called direct must take this revolving field definitely into account.

The fact that the rotating field method is not conveniently applicable to the single-phase commutator motor is not surprising. Such a machine is not an induction motor, the essential principle of its action being the same as that of the continuous current motor.

In conclusion I should like to express the opinion that in view of the undoubted difficulty presented by the theory of the single-phase induction motor it is advisable both for engineers and for teachers to neglect neither of the two methods of treatment referred to in Mr. Lebovici's interesting paper. Both methods are correct, and when complete they are equivalent.

F. M. BENTON
Northampton Polytechnic Institute
London, Eng.

Questions on the Economic Value of the Overhead Grounded Wire

BY E. E. F. CREIGHTON

Associate A. I. E. E.

General Electric Company, Schenectady, New York

Review of the Subject.—*Overhead grounded wires have been in extensive use since the construction of the earliest transmission circuits. The fundamental theory of their protective value is based on Faraday's ice-pail experiment. As the resulting law goes, there is no electrostatic field emanating from the inner surface of a charged hollow conductor. The parallel grounded wires do not surround the power wires. Consequently the protection of these grounded wires against induced electric charges by thunder-clouds, is only partial—usually of the order of 25 to 40 per cent.*

It might be erroneously inferred that several decades of use of the overhead grounded wire had established by practise its value. The several factors involved in its use do not lend themselves easily to experimental observations. For example, power lines extend over hundreds of miles, while any particular induced charge is localized at some point in these vast distances. Taking into account the brief period of a lightning stroke, the unwilling observer stands a small chance of being near the point of discharge. Furthermore, thunder-clouds differ from one another. Still further, at the instant the lightning bolt takes place the distance from the thunder-cloud to the power wires varies quite indefinitely. In fact, there is a long list of difficulties involved in experimental observation of the effect of cloud lightning on power wires. As a result, except for a few small-scale experiments performed in the laboratory, knowledge of the subject is confined almost entirely to theoretical analyses. This paper is an addition to the theory but it is not of a mathematical nature.

Conditions of protection have changed in recent times. Therefore, in this paper the definite conclusion is drawn that the expense of overhead grounded wires on wooden pole lines is, in general, an economic waste. In particular cases it may be justified. On metal tower construction the use of the overhead grounded wire is, in general, fully justifiable.

The analyses in this paper were made for presentation to a Public Service Commission. This Commission, on reconsideration, reversed its order that an overhead grounded wire should be installed on a 13-kv. transmission circuit supported on a wooden structure.

Review of New Material. — References to the technical literature on the subject of overhead grounded wires are given in the bibliography which follows the paper. For those familiar with the subject there is given below a brief review of several parts of the paper which emphasize the recent additions to the knowledge of the subject.

1. Analysis of the functions of the overhead grounded wire under nine distinct parts, where previously only three functions were classified.

2. Recognition that the requirements of the overhead grounded wire are less than formerly. In the early days the overhead grounded wire was needed to assist lightning arresters, but today the arresters have sufficient discharge rate not to require the assistance of the grounded wire.

3. Analysis which points out that the overhead grounded wire protects only for a specifically limited range of voltage. It is no protection for induced voltage below the normal arc-over value of the insulator, and no protection when the induced lightning voltage is sufficient to arc-over the insulator in spite of the presecen of the grounded wire.

4. Appraisal of the weight to be given to each of the nine functions of the overhead grounded wire and considerations of its cost lead to the conclusion that, barring exceptional cases, it is an actual detriment when placed on semi-insulating structures, such as wooden pole lines. Used here the overhead grounded wire lowers the arc-over voltage of lightning.

5. The overhead grounded wire with considerable sag cannot be considered as a mechanical support to rigid tower structures.

6. Analysis is given to show that the overhead grounded wire on a metal tower line loses its function in protecting arc-over of insulators in proportion to the earth resistance at the legs of the tower. Experimental proof is not available at present. Also the values of ohmic resistance at tower legs which will destroy the protective value of the grounded wire to prevent arcing over insulators are not available. Metallic connections of a tower of high earth resistance to an adjacent tower of low earth resistance have little if any beneficial effect in protecting the insulator from lightning. The horizontal distance is too great.

7. On a grounded neutral system experimental tests of a short circuit of a single phase showed the necessity of connecting the overhead grounded wire to the station earth connection to reduce the earth resistance to a safe value. Otherwise the neutral rose so high in voltage during short circuit as to jump-spark into the low-voltage wiring of the station, blowing fuses and affecting the switch control.

8. Looking to the future, the overhead grounded wire, by lowering the general resistance to earth of all towers to the passage of accidental short-circuit current (of the generator, not lightning) will have a valuable function in connection with arc-suppressors. This function is really the one already recognized as an aid to proper operation of relays.

A General Conclusion.—As applied to metal structures the analyses do not bring out any detrimental function of the overhead grounded wire. It is not condemned in this use but attention is directed to some of its limitations. Further study is desirable. The cost of the overhead grounded wire is a considerable factor. At maximum it now seems that for many or most cases one grounded wire only may be needed. Exceptional cases and conditions must be decided by detailed considerations.

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Definitions

The term "overhead grounded wire" is currently used to mean the extra wire, grounded at many or all of the supports, that is strung parallel to the power wires on an overhead transmission. The "aerial grounded wire" has also come into use to mean the same.

"Overhead" is a term more commonly used by electrical engineers of transmission lines than "aerial" as applied to grounded wires. Aerial, perhaps, is the more general term. "Overhead" usually carries the idea to most people as being above the power wires although it means literally above the head. Overhead may, therefore, mean literally underhung or overhung relative to the power wires.

The vertical grounded wire—the connection between the overhead wire and the earth contact—is used on wooden poles or other types of semi-insulators. As such it is sometimes referred to as the pole wire.

Earth connections are the metallic parts extending into the earth. The earth connection may be in the usual forms of tower legs, driven pipes, or coiled wire around the base of a wooden pole.

The lightning rod is any projection of conductor in the vertical plane above the horizontal grounded wire.

In review, the four parts are: 1, horizontal overhead grounded wire; 2, vertical grounded wire; 3, earth connections; and 4, lightning rod (seldom used).

Historical

It is not the object here to trace the growth of use of the overhead grounded wire but simply to bring out some salient points and to give a bibliography of the scientific discussions of this subject. The earliest overhead grounded wires were barbed wires, such as used by farmers. The Bessemer steel used in this wire (when used in the relatively long spans between poles) was so unreliable in mechanical strength that the wire gave much trouble from breaking and short-circuiting the power wires. It was early recognized that *the barbs on the wire had no practical value in giving protection against lightning strokes.* There was erroneous theory advanced by lightning rod experts that point discharge by corona materially lessened the danger of direct stroke. The theory seems unreasonable.

There have been few attempts to prove practically the value or uselessness of the overhead grounded wire but none of these has been convincing unless perhaps one instance given in a recent N. E. L. A. report, because of the variableness in the lightning storms and the impossibility of getting an exact comparison by any of the data collected. The reasonable basis of the good effects of the overhead grounded wire has resided mostly in the theoretical consideration. It is a comparatively simple matter, although laborious, to calculate the quantity of electricity induced on a transmission wire with and without a parallel grounded wire. These figures are quite definite. The theory has been substantiated by electrostatic measurement. While it was formerly the opinion of the majority of leading electrical engineers that the overhead grounded wire fully warranted its cost under certain conditions of installation and for a definite range of voltage, it is well, nevertheless, to make note of the fact that the practise is not founded on definite experimental knowledge of the actual installations. There are many doubters of its value nowadays.

Introductory—Mechanical vs. Electrical Factors

The primary requisite of an aerial electrical line is to be ready to supply electrical power continuously. To do this two natural and fundamental conditions must exist, namely that the line must be suitably insulated to withstand all impressed voltages and, second, that it must be mechanically durable. The mechanical durability involves the mechanics of material, their strength, characteristics, etc. While the factors involved in the mechanical side of the line construction are of prime importance, it is not the object in the present discussion to treat of them except as the type of mechanical construction influences directly the dielectric strength of the insulation. To confine the discussion as much as possible to the electrical side, it is assumed initially that due weight has been given to all the engineering factors and the choice has been made of construction with porcelain, glass, wood, cement, concrete (with or without reenforcing), or steel, together with such impregnating or painting treatment as the conditions demand. The mechanical structure may then be analyzed into types according to the insulation it affords against electrical failure. Steel structures represent one type, wooden poles represent the other.

The prime object of the present discussion is to treat the electrical side, especially in the matter of insulating against lightning and the line potentials. The specific subject to be treated is indicated by the title, "Overhead Grounded Wires." It is of course, impossible to treat of the aerial wire by itself, as the whole aerial system of electric wires and supports must be taken into account as in any engineering structure. The first question we must ask ourselves, then, is: What is the object in using an overhead grounded wire?

The answer to this question differs now from what it was in earlier days of transmission. This fact is one of the excuses for this paper. In early days lightning arresters were uncertain and of low discharge rate. Insulation was weak and not wisely distributed. As a result, the overhead grounded wire was desirable to lessen the duty on lightning arresters. This necessity has disappeared. While it is not claimed that the proper value of discharge rate for an arrester is

exactly known for every application, each arrester of the valve type is capable of adjustment to a much higher value than used at present which, in the limitations of present knowledge, seems to be sufficient.

Speaking from the electrical standpoint solely, a partial answer sometimes made is: To lessen the electrostatic induction on the power wires caused by thunder-clouds. Faraday in his "ice pail" experiment showed that no electrostatic lines of force extend into a closed conductor. The earliest writers on protection of lines state that if an aerial transmission line could be entirely surrounded by a metallic sheath, such as is done with the lead encasing sheath of an electric cable, no electrostatic induction from the clouds on the power wires could take place. Such a construction has not been found economically feasible. An amelioration only of the induced voltage has been gained by the use of one to three aerial grounded wires. Lead-encased aerial cables are common practise in telephone construction. In power transmission such practise is limited by the cost of electric cables and the difficulties of obtaining suitable insulation material for very high voltages.

A more complete analysis than has previously been given of what can be expected of overhead grounded wires follows. It is not the ultimate of the possible detail analysis but is made from the viewpoint of the engineer in the process of determining the need, the value, and the desirability of this protective device.

Functions of the Overhead Grounded Wire

The functions of the overhead grounded wire may be put into nine main divisions, as follows:

1. *To reduce the quantity of electricity and the energy induced on the power wires by a lightning cloud and to reduce the voltage of a traveling wave* (with its energy located between lines and ground) which was previously the "bound" charge held by the electric induction from the overhanging thunder-cloud. This function reduces the charge and energy that reach the apparatus and arresters. In the usual location of the overhead grounded wire it gives no appreciable protection against those internal surges which have their energy located between power wires.

2. *As a protection of insulators against flash-over.* This second category is to be distinguished from the first, especially in such a respect as involves the time. If flash-over takes place it should happen while the surge energy is crowded toward a point on the line, a time presumably coincident with the movement of charges in the cloud, and not after the charge splits into two parts and travels away from this point. This theoretical matter will be taken up again under the heading "Steel Structure."

3. In some cases the use of the *overhead grounded wire as a mechanical support between towers* is of greater value than its electrical protective functions. Occasionally, however, during sleet storms accompanied by transverse winds it is a disadvantage in throwing an extra side pressure onto the towers. Even its value as a longitudinal mechanical support for rigid towers is questioned later.

4. The overhead grounded wire has in some cases a very useful function in *forming a low-resistance earth connection.* There are four aspects to this factor: (a) As a uniform earth connection the parallel grounded wire may be used in *localizing faulty insulators.* (b) Where the neutrals of the power circuits are grounded the lesser resistance of earth connection is an aid *during accidental single-phase short circuits in preventing a rise in voltage of the station ground* and consequent damage to the low-voltage wiring of the stations, including circuit-breaker control, lights, excitation, etc. This is an important function only recently recognized. Some experimental experiences will be described at some future time. (c) Where towers are set in dry earth or rock and thereby partially insulated, the overhead grounded wire may become valuable in *connection with the arc suppressor.* The multiple earth connections supply good conduction to earth in spite of those towers that are practically too insulated to give proper operation of selective relays used in conjunction with the suppressor. (d) There is also a probable, remote value, in cases of dry or rocky foundation at towers, relating to the question of *danger to human life* for anyone standing on the ground and in contact with the tower when an insulator on the same tower is accidentally short-circuited.

5. *The overhead grounded wire absorbs a part of the energy of a traveling wave on the power wires.* It thus lessens the discharge current through lightning arresters when the lightning cloud is at a distance from the station.

6. When used *near a station* and when a *direct stroke* occurs near the station, it is possible that the overhead grounded wire lessens the chance of high voltage entering the station.

7. In the type of distribution circuit known as the *three-phase, four-wire* system the fourth wire is usually grounded at one or more places. The primary object in the use of this parallel grounded wire is not for protection against lightning. The use is economic in origin. Standard 2300-volt transformers Y-connected give a line voltage of 4000 volts. The higher voltage of transmission permits a saving in copper of the wires, if the power delivered is greater than can be carried on the minimum size of wire chosen by reason of mechanical strength. There is also a saving in lightning arresters at single-phase installations. Only one main arrester is used at the transformer of a four-wire system where two main arresters are needed for a single transformer on the three-wire system.

Incidentally the presence of the fourth wire de-

creases the lightning voltage induced on the remaining power wires.

8. *On single-phase short circuits,* with neutral grounded, the overhead wire acting as a partial return wire *reduces somewhat the inductance.* This reduction may be somewhat beneficial or detrimental, according to conditions and requirements of circuit breakers and relays.

The overhead grounded wire lessens the stray electric field which would extend to a parallel telephone or other low-voltage line and thereby lessens somewhat the inductive interference which must be neutralized by transpositions in both circuits.

Comments Before Noting the Ninth Factor. The eight foregoing functions of the overhead grounded conductor, insofar as they are performed, are preponderatingly beneficial in their general effect on an electrical transmission (not to say economically desirable). The ninth and last tabulated function may, in some types of construction, become very detrimental.

9. *The overhead grounded wire brings the zero potential of the earth from its surface to the height of the overhead grounded conductor in the near meighborhood of the power wires.* This lowering of the potential of lightning induction in the neighborhood of the power wires is the fundamental reason for the decrease in the quantity of induced charge as described in the first enumeration.

The nearer the grounded wire to the power wire, the less the induced static charge and voltage by thunder-clouds on the power wires. *But the reduction of this lightning potential is not the ultimate desideratum in using the aerial grounded wire. The real aim is to lessen the number of flash-overs at the insulators.* For purposes of illustration the effect of different distances between power wires and conductors at zero potential will be discussed. In the extreme minimum, if the grounded wire is placed too close to the power wire its presence increases the number of flash-overs, due, not to lightning, but to the power potential itself. From this consideration alone then a mechanical clearance throughout the spans between supports must be maintained sufficient to give a suitable spark voltage to the power wires. The spark potential between the power wire and the parallel grounded wire should, in general, be greater than between the power wires and their conducting support at the insulator. The object of this ruling is to avoid damage to the grounded wire by the tendency of the craters of accidental arcs to melt the wires in two. Such safe spacing is easily obtained for grounded wires used on metal towers. It is seldom attained on wooden-pole construction and other means are necessary to avoid damage by craters. A discussion of these means will be deferred.

Relation of Overhead Grounded Wires to Cloud Lightning

Erroneous functions have sometimes been attributed to the overhead grounded wire. To counteract these speculations, occasionally heard, some statements will follow of what the overhead grounded wire does not do.

It has no effect in lessening the formation of electric charges in the clouds.

It does not increase or decrease the number of lightning flashes from the clouds.

It is not known to have any effect in either dissipating or producing appreciable charges in its neighborhood. Even the ionization produced by corona at the surface of a wire must be rapidly lost at a small distance from the wire. Otherwise, the power potentials would spark from wire to wire. If very high potentials in the future, by some unknown, incipient effect, are going to ionize or deionize the atmosphere to a radial distance sufficient to have an effect on a lightning stroke, it is a matter to be determined by future research. Even if some new very high potential power circuit gave evidence of gradually discharging atmospheric charges in its neighborhood, rapidly traveling thunder-storms (the most common form) would still be blown over the power lines.

The electrostatic potential rise in a thunder-cloud usually precedes a discharge by only about one minute. This is a short period in which to expect any relief of strain in the atmosphere around a transmission line by any known corona effect produced by the thunder-cloud.

So far as known at the present time, the value of the overhead grounded wire is entirely in relation to the power wires which it parallels.

It is presumed that the overhead grounded wire parallel to the power wires probably exerts slight effect in reducing the voltage induced electromagnetically by those little-known rare discharges which parallel the transmission line but take place from cloud to cloud.

Pertinent to what the overhead ground wire cannot do is an effect sometimes attributed to iron deposits in the neighborhood of storms. In a court-room the statement was made that iron deposits increased the frequency and severity of electrical storms. This statement is erroneous although it has enough element of fact in it to resemble the truth. The electrical charges gather in the atmosphere independently of any formation under the surface of the earth. However, any condition of electrical conduction which lowers the resistance in the path of the lightning bolt increases its current and prolongs the duration of the discharge. The conduction of bonded rails of railways produces burning effect in lightning arresters, having spark gaps, notably more severe than when there are no rails to gather in the radially traveling charge on the earth's surface. Salt swamps it might be argued would have the same effect. The writer has no data on the path the lightning might take either along the surface or (by leaving the static pull)

spreading to better conducting layers at more or less depth beneath the surface. Incidental to this subject, a study of earth pipes showed that the whole earth became a good conductor at short distances from the contact with the pipe, due not to high conductivity, but to vast cross-sections. There are, in fact, several unknown relations in the discharge path of lightning that form a field for speculation, such for example as the ohmic resistance of the feeding arteries in the cloud, the main artery, the earth contact, and the unknown path of the gathering currents on and in the earth under the discharging cloud.

Detrimental Effect of Grounded Wires on a Semi-Insulated Structure

The very presence of an overhead grounded wire anywhere on a well-designed wooden-pole structure reduces the spark potential to lightning stroke. Its presence must therefore, in this particular respect, be considered detrimental. It is detrimental somewhat in proportion to the decrease it causes in the spark voltage between the power wires and ground. For example, a normally insulated wooden-pole line, without overhead grounded wires, has a spark voltage to lightning proportional to its height above the surface of the earth. It is of the order of magnitude of 10 to 20 meters (33 to 66 feet). The distance from the power wire to the grounded wire is usually of the order of magnitude of 1 to 2 meters (3 to 6 feet). Thus the presence of the grounded wire on a wooden-pole line reduces the spark potential of induced lightning stroke to one-fifth or one-tenth. The result of this decrease is shown in a greater number of insulator flash-overs due to lightning.

To summarize this discussion crudely in a single sentence: Placing an overhead grounded wire on a well-designed wooden-pole line lowers its spark potential 80 to 90 per cent in order to lower the induced potential of lightning by a value of the order of 25 per cent.

Relation of Grounded Wire to Direct Stroke

So far as the aerial grounded wire carries zero potential above the surface of the earth it increases the possibility of direct strokes on the line. As a matter of judgment this increased probability of direct stroke is entirely negligible if not absent where metal towers are used as a support. The tower will naturally take the discharge of the direct stroke, other things being equal. The presence of the grounded wire between towers slightly increases the possibility of a stroke finding a path to the circuit.

In the case of wooden or other insulated supports the presence of the vertical wire actually decreases the distance from the earth to the lightning stroke by 10 to 20 meters in a vertical direction. If the direct stroke comes so near the line that this decrease in distance shortens down appreciably the path of lightning stroke to earth it will, in proportion, invite the discharge to strike the grounded pole rather than some other object in the neighborhood. For example, a metal mast of a ship at sea in a thunder-storm will "draw" a lightning stroke to it from a considerable radius because it is the only high point on a smooth surface. Analogously a wooden pole having a vertical grounded wire and located in a flat country should slightly "draw" a lightning stroke that happens to come in the near neighborhood. Direct strokes on transmission lines are relatively rare. This being so how are we to give weight to the factor which has a possible slight effect on increasing the rare event?

In cases of direct stroke on a wooden pole the vertical wire on the pole prevents splitting of the pole by the explosion coming from the sudden vaporization of the moisture in the wood by I^2R of the lightning current and ohmic resistance of the wood. The writer has never heard of but one case where the pole was destroyed as a support. Many cases of slight and serious

Fig. 1—Newly Erected Pole Struck by Lightning, August 7, 1916, Newton, Utah.
By courtesy of the Power Company.

damage to a pole are known. Fig. 1 shows severe damage to a pole by lightning. This experience brings up the question, important to the best type of construction, for power lines, is it worth while to invest in vertical grounded wires on poles, and thereby decrease the insulation of the line against lightning, to save that apparently rare case of complete destruction of a pole? Those who may add information, either in discussion to the present paper or in those valuable reports of committees such as in the N. E. L. A. now gathering information, should make a distinction between poles burned by dynamic current and poles destroyed by lightning. Lightning does not carbonize the wood—it explodes the moisture. The distinction is desirable because the cure is different. The vertical grounded wire, while preventing the damage by a direct stroke of lightning, increases the accidental burning effect on crossarms by the power voltage by increasing the potential gradient along the crossarms. When the vertical grounded wire short-circuits the high resistance of the wooden pole it throws the line-

to-ground potential on the part of the crossarm which is situated between the wire in accidental connection with the crossarm, and the bolt at the junction of pole and crossarm. This distance is of the order of one meter. On the other hand, if no vertical grounded wire is used the same potential is distributed over the sum of the distance along the pole and crossarm. The greater resistance to earth decreases the leakage current and lessens the risk. This distance is of the order of 4 to 7 meters.

Overhead Grounded Wires on Wooden-Pole Structures

Attempts to induce public service commission to specify the use of overhead grounded wires on wooden structures has raised the serious question whether the overhead grounded wire so used is not an economic waste. On comparatively low voltages on wooden poles it surely is a loss unless it is installed for a purpose other than lightning protection. When the question is raised, at what higher voltage on wooden-pole lines should overhead grounded wires be used?—it requires to answer it a review of what useful functions it may perform.

However, before questioning in detail, distinction must be drawn between mechanical and electrical consideration. Wooden poles carrying grounded insulator-pins constitute admittedly a wooden structure from a mechanical standpoint, but it is a metallic structure from an electrical standpoint. Electrical protection of overhead grounded wires is under discussion. To discuss these questions logically the four grades of insulation below the porcelain insulators must be included as factors and each given its proper weight in the appraisal. These grades are:

(a) Nonmetallic pins, crossarms, and poles.
(b) Metal pins, nonmetallic crossarms, and poles.
(c) Metal pins, metal crossarms, nonmetallic poles.
(d) Grounded metal pins

Even the foregoing analysis is not definite enough unless by the two mechanical designations, metallic and nonmetallic, the idea of conduction and a degree of high resistance respectively are understood. For conditions attending the use of suspension insulators the distinction should likewise be made, but with different words because it is the cap and not the pin of the suspension insulator that is mechanically connected to the crossarm.

Grounded metal pins fall in a class with the metal towers and are not under analysis at present. The first three classifications, viz., (a), (b), and (c), are near enough alike to be treated with approximation in one class for the following analysis.

An attempt will now be made to apply in detail the general analysis, already given in nine functions, to the particular use of an overhead grounded wire on a wooden-pole structure.

First Function. On nonmetallic structures the overhead grounded wire is not needed as an aid to lightning arrester.

Second Function. Instead of protecting, it actually lowers the arc-over of insulators subjected to a lightning voltage.

Third Function. The overhead grounded wire is not needed for mechanical strength where pin-type insulators are used. It is detrimental in increasing the wind and sleet load.

Fourth Function. It may find some use as a low-resistance earth connection. Is it needed to localize faulty insulators? Not where wooden pins are used; and is of possible but doubtful economic use where metal pins are used. The vertical grounded wire makes a grounded pin where metal crossarms are used and therefore falls in the other classification. As making a better ground connection for a system using the grounded neutral the overhead grounded wire may be valuable, but for it to act in this capacity it is not necessary to install it for the full length of the power line but only near stations. Furthermore, as such, it is better to hang it under, rather than over the power wires. So located it cannot, after corroding with age, fall on the power wires. As an auxiliary to the arc suppressor (now under development) it seems of no particular use. It does not safeguard human life—the wooden pole is safer.

Fifth Function. In the fifth function as an absorber of traveling waves the overhead grounded wire is useful but not necessary. It is not needed to aid distant arresters. It is not necessary for isolated installations of transformers along the line which has no arresters. There are other and cheaper ways of getting protection.

Sixth Function. The overhead grounded wire may be used if desired near a station, with special precautions in construction, for use against direct stroke and yet save the expense for the rest of the lines.

Seventh Function. At present the three-phase, four-wire economics are not under discussion.

Eighth Function. As a return wire and a parallel conductor to lessen the scattered electrostatic field, the overhead grounded wire has its normal useful function. Except for very high voltage, prominent harmonics, and near parallel telephone lines this factor will seldom justify the expense.

During accidental grounds the value of the overhead grounded wire in decreasing interference with parallel telephone systems is reduced to a small, but unknown value by the predominant electromagnetic induction of the return currents in the earth.

Ninth Function. In bringing the zero potential of the earth from its surface to the height of the power lines the installation of an overhead grounded wire on an insulated structure is very detrimental. It reduces the arc-over voltage from the power wire to ground. This is the factor which seems sufficiently prominent to condemn the use of the overhead grounded wire on wooden structures.

Conclusion. Having considered briefly each of the separate items, the conclusion is reached that the overhead grounded wire is, in general, a detriment rather than an asset to a semi-insulated or high-resistance pole-line structure. It is impractical to consider here every possible detail but the endeavor has been made to mention or indicate all the factors, so that for any particular installation, engineering basis for the installation or taking down of an overhead grounded wire may be determined.

Steel Structures and the Overhead Grounded Wire

The ninth function enumerated for the overhead grounded wire which is so objectionable to wooden pole construction is not so for steel structures. The metal tower or pole brings the zero of earth potential to the height of the line in the neighborhood of the insulators. The overhead grounded wire adds nothing more to this detrimental condition. All of the first eight functions enumerated for the overhead grounded wire are more or less beneficial and none is detrimental. Specifying the use for metal structures will depend on figuring enough intrinsic value to pay for its cost. A review of some of the crucial factors follows:

Such effective protective apparatus can be installed at the stations as to make the use of the overhead grounded wire all along the line of no particular need to help the arresters.

Suppose the overhead grounded wire is considered as a mechanical support in the accidental emergency of a broken power wire. How much good can it do? Can the overhead grounded wire prevent mechanical damage to the tower sufficient to maintain service on other parallel circuits? Considerations of the flexible structure support are set aside. The overhead grounded wire is an intrinsic part of it. The usual four-legged tower is a relatively rigid support. The overhead grounded wire itself is a flexible horizontal support. It sags loosely between towers. Can a tower top move, without damage to itself, far enough in the longitudinal direction to utilize the increase in tension of the overhead grounded wire? If not, the overhead grounded wire loses its value in this function. Will enough mechanical damage be saved to the local structure and other parallel circuit or circuits on the towers to warrant the cost and depreciation of the overhead grounded wire in its entire length along the tower line?

Will the overhead grounded wire decrease the number of flash-overs of the insulators? According to the theory given by the writer in 1916 (Transactions A. I. E. E., p. 945) it may not have much value. This theory has not been refuted, nor even questioned. It states that the voltage of the induced charge on each power wire by thunder-clouds is decreased by the presence of a parallel grounded wire only by the passage to earth of the initial charge on the grounded wire and its replacement by an induced charge of the opposite sign by the lightning charge on the power wire. Under some conditions it is questionable whether this "increased capacitance" by the grounded wire becomes active in reducing the induced potential in time to save the over-stressed insulator from arc-over. This matter will be discussed further.

Among the factors which determine the efficiency of the grounded wire in preventing arc-over of insulators are some which are obscure, due to lack of both theoretical and experimental data. The time involved in the movement of the charges in the clouds is unknown. De Blois in 1914 gave some oscillograms which showed that some of the effects of potential changes in the cloud were very slow as compared to spark lag of insulators and gaps. So far as this slow movement obtains it is favorable to effective action of the overhead grounded wire. It is understood, however, that the final stroke to earth takes place with great rapidity but no one knows that this velocity in any way approaches the velocity of light which is the approximate velocity of travel of a free charge along a transmission line. It is hoped that some of Prof. Harris J. Ryan's unpublished work on discharges will add useful information to this subject.

At any rate, we know that the circuit of the cloud lightning is long as compared to the circuit of the grounded wire. This much information would lead us to infer that, insomuch as affected by distance of travel, the charge on the grounded wire would have plenty of time to pass to the earth while the main bolt is taking place from cloud to earth.

There is a factor, however, in the grounded wire circuit which has not been given practical attention, namely the resistance of each tower to earth. There are many dry localities and even rocky localities in wet countries where the ohmic resistance of the earth connections of particular tower legs is extremely high. This resistance limits the rate of discharge of the freed charge on the grounded wire. In so doing it decreases the effect of the grounded wire in preventing arc-overs of insulators. While a calculation of the theoretical value of the overhead grounded wire with well grounded legs gives a potential ratio with and without this protection of about 70 per cent (a protection of 30 per cent) for a circuit of approximately the same dimensions as the Mississippi River Power Company's 110-volt line, a high resistance of earth connections would reduce this protection from 30 per cent to an unknown smaller value.

A proof of the small value of the overhead grounded wire to prevent arc-overs of insulators can be given by a simple arithmetical example.

Suppose the insulators in use on a line can be arced over by a lightning potential of 200 kilovolts. Suppose furthermore, that the tower legs have a high earth resistance and therefore the presence of a grounded wire would reduce the induced potential on insulators

by only 12 per cent. It would then require an induction equivalent to 227 kilovolts to arc-over an insulator where the grounded wire is in use (200 ÷ 88 per cent = 227). If the induced voltage is less than equivalent to 200 kilovolts the presence of the overhead grounded wire has no value in preventing an arc-over. In fact, there would not be an arc-over if the protective wire were absent because the induced voltage is below the arc-over voltage of the insulator.

On the other hand, if the induced voltage is equivalent to 227 kilovolts the presence of the overhead grounded wire gives no useful results, because an insulator will arc-over in spite of the presence of the overhead grounded wire.

For all induced voltages below 200 kv. and above 227 kv. the parallel grounded wire, with a 12 per cent protection, has no value in preventing arc-overs. It is only over the small range between 200 kv. and 227 kv. that it would be effective. The chosen percentage of protection may actually be higher or lower according to the earth resistance of the particular tower where the maximum lightning voltage concentrates. A distinction is made in passing—while the overhead grounded wire decreases the general resistance to earth for power currents, it does not do so for lightning. Theoretically there is not sufficient time for the charge to flow to adjacent towers before the strain on the insulators produces its effect.

If this proof is sound it shows why observations made on transmission lines with and without overhead grounded wires have given so few useful data.

There is another useful viewpoint. If, instead of assuming the pessimistic conditions of protection, it is assumed that the tower legs are connected to earth with high conductance and other attendant conditions are such as to give the overhead grounded wire its maximum calculated value of 30 per cent protection, it may be considered as a very economical equivalent of an increase in dielectric strength of the insulators by somewhat less than 30 per cent; in other words, that the grounded wire is equivalent to putting extra disks on every line on the tower. The use is limited to lightning voltages. Protection is not given by the grounded wire against internal surges or, obviously, against failure of individual disks in a string.

On some general measurements made between two tower lines, the writer was led to believe that the usual resistance of earth connections of towers was high rather than low. Estimates made from related data and laboratory experiences indicate a restricted if not doubtful protection of insulators from arc-over by the overhead grounded wire when the insulators are on towers of high earth resistance. There are not enough data at the present time to give definite solutions to this problem. It would seem, however, that the problem is solvable.

To summarize the points gained so far in the analysis of metal support structures, the overhead grounded wire is not detrimental but is unnecessary as an aid to lightning arresters and it may have a small average useful range of protection for flash-overs of insulators.

On the other hand, for one purpose it seems there is going to be an incontestable use for the overhead wire on metal structures. This use is in connection with the arc suppressor which seems destined to become a standard device where aerial wires are used. As matters of development stand today the conditions needed are either very high resistance to earth, such as found on wooden-pole lines, or very low resistance to neutral such as can be obtained on metal tower lines linked in metallic contact by the overhead wire.

If the conditions are such as to make its use solely to lower the earth resistance in general, why not use it near the telephone line and even as a messenger wire? Induction on the telephone can be modified thereby. It will surely lower the voltage to earth induced on the telephone lines and make them safer to handle.

The work of this paper represents several days of concentrated effort. This is not enough for the complexity of the problem. The analysis is incomplete. More and specific experimental data are needed—data both from the laboratory and from the field.

The reasoning should be carefully scrutinized, and criticised especially in regard to its applicability to special cases.

Significance of the Analysis

The course of reasoning brings the conclusion that overhead grounded wires and vertical grounded wires on semi-insulating structures, such as wooden poles, are in general detrimental. On metal structures no technical function is found detrimental. If protection against arc-over of insulators is, as it appears, affected by the ohmic resistance between tower legs and earth either the effectiveness of the overhead grounded wire may be increased by attention to earth connections or this function of the grounded wire is sufficiently decreased to allow the grounded wire to be used lower down on the tower in another function. The relation between the earth resistance and the decrease in protection to insulators is yet to be determined.

Bibliography

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Note. The principal papers in the following list involving the theory of the overhead grounded wire are: 1 *by R. D. Mershon* (1903) *with its discussions;* 3 *and* 4, *discussion by Dr. Steinmetz* (1905) *and* (1906); 5, *by R. P. Jackson* (1907); *and* 12, *by E. E. F. Creighton* (1916).

1. Mershon, R. D. The Grounded Wire as a Protection against Lightning. Vol. 22, 1903, p. 331, 2000 words.

Discussion (5800 words) by Messrs. Scott, Perrine, Mailloux, Wurts, Thomas, Kennelly, Lincoln, Woodward, Rushmore, Kelsch, Kelly, Hayward, Waters, Curtis, Jackson, D. C., Hammer, Blanck, and Mershon.

2. Report of Committee on High-Tension Transmission. Questionnaire on Lightning Protection. Vol. 23, p. 592. (500 words on overhead grounded wire, practise but no theory).

Discussion largely overhead grounded wire (1400 words) by

Messrs. Finney, Mershon, Junkersfeld, Arnold, Schuler, Storer, Perrine, Clark, E., Jackson, W. B., Neall, and Lyman.

3. Discussion by Dr. Steinmetz, Vol. 24, 1905, p. 995. (400 words).

4. Discussion by Dr. Steinmetz, Vol. 25, 1906, p. 428. (600 words.)

5. Jackson, R. P. Potential Stresses as Affected by Overhead Grounded Conductors. 1907, Vol. 26, p. 873. (2800 words, 7 diagrams of equipotential curves).

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6. Vaughan, J. F. Comparative Tests of Lightning Protection. Devices on the Taylors Falls Transmission System. Vol. 27, 1908. Subhead: Overhead Grounded Wire, 1 page, (400 words).

7. Neall, N. J. Studies in Lightning Performance (1907). Vol. 27, (1908) Subhead: Overhead Grounded Wires, p. 429, (400 words).

Discussion of both the above papers, only part of which is on overhead grounded wire (3600 words) by Messrs. Buch, Lincoln, Vaughan, Thomas, Creighton, Scott, and Moody.

8. Rowe, Norman. Lightning Rods and Grounded Cables as a Means of Protecting Transmission Lines Against Lightning. (2500 words, 4 photographs, 3 of line towers, 1 of broken insulator). An installation in practise.

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10. Nicholson, L. C. A Practical Method of Protecting Insulators from Lightning and Power Arcs (10,400 words). A small but important part relates to overhead grounded wires. 1910, Vol. 29. p. 573.

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11. Short discussion of overhead grounded wires in five distinct papers beginning with a questionnaire of the High-Tension Committee, June 1911, Vol. 30 (12,000 words), by Messrs. P. H. Thomas, J. P. Jollyman, W. S. Lee, M. Hegben, and P. T. Hauscom, respectively.

12. Creighton, E. E. F. Theory of Parallel Grounded Wires and Production of High Frequencies in Transmission Lines (1916), Vol. 35, Part 2, p. 845 (17,400 words) 33 illustrations, 1 table, 41 mathematical equations.)

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OTHER SOURCES

13. The Protective Value of Grounded Wires (Translated title), W. Peterson of Darmstadt. *Electrotechnische Zeitschrift.* Jan. 1, 1914. Mathematical calculations of the percentages of protection afforded by parallel grounded wires.

14. Nat. Elec. Light Assn. Report of Overhead Systems Committee, T3-21, June 1921. Price: Members $2, nonmembers $4. (On overhead grounded wire, 12,000 words). This is an analysis of a questionnaire on practise. It is the most exhaustive and valuable collection of existing practise, experience and opinion yet made.

FIRST REPORT OF THE FEDERAL POWER COMMISSION

The first annual report of the Federal Power Commission which recently has been issued, clearly discloses the fact that the development of hydroelectric power will play an important part in the industrial development of the United States for many years to come.

Prior to 1920 there was comparatively little water power development on the public domain or on navigable streams due to the fact that the legislation then on the statute books was, because of its limitations, considered unworkable. The flood of applications which has followed the passage of the Federal Water Power Act of 1920 and the projects on which, notwithstanding the industrial depression and the uncertain financial situation, construction has already started under license issued by the Commission is abundant proof, both of the extent to which former legislation stood in the way of power development and of the generally satisfactory character of the present law.

The urgent need of conservation of our coal, gas, and oil supply for power purposes will now be met by gradually supplanting these agencies wherever possible by the use of water power.

In the 16 months following the passage of the Federal Water Power Act there were filed with the Commission 185 applications for preliminary permit and 85 applications for license to develop water power, 260 in all, which after deducting conflicting applications and those rejected or withdrawn, aggregated the stupendous totals of 11,060,000 primary and 5,766,000 secondary horse power or 16,826,000 horse power of estimated installation. This is twice the water power which has been developed in the United States to date, and exceeds the combined potential water power resources of Norway, Sweden, Finland and the Arctic and Baltic drainages of Russia. It is 70 per cent greater than the combined resources of France and Italy. It is from five to six times greater than the aggregate of all applications filed with the Federal Government during the preceding 15 years.

The country could not of course, absorb at once all the power projected for development, and many applications may never be carried out. It is the belief, however, that the greater part of the horse power involved will eventually be constructed. To complete the projects applied for will require capital exceeding in the aggregate two billions of dollars. The collateral expenditures for distribution systems, for customers' installation and in accessory industries will be several times greater.

Much time and care has been devoted during the year to compilation of the rules and regulations governing administration of the Federal Water Power Act. The first ten regulations included matters which had been covered in considerable degree by regulations under earlier laws; the remaining subjects to be covered were largely new.

Current Locus of Single-Phase Induction Motors

BY J. K. KOSTKO
Associate A. I. E. E.
Wagner Electric Manufacturing Company, St. Louis, Mo.

Review of the Subject.*—The principal applications of the current locus of single-phase induction motors are the predetermination of the performance of a projected motor on the basis of its constants, and the determination of the performance and constants of an existing motor on the basis of a few simple tests. The first question is particularly attractive to a mathematically trained mind, because, with constants considered as known, it is simply a problem of mathematics; a great amount of work has been done to find and perfect its solution. The second problem is, perhaps, more difficult than the first. Its thorough treatment requires not only the knowledge of the solution of the first problem, but also the ability to make use of more or less complicated combinations of constants given by tests instead of the constants themselves; moreover, the exact solution usually cannot be obtained, and one is obliged to make certain incorrect assumptions, drawing upon the practical experience to set proper limits to these inaccuracies; for this reason, perhaps, the second problem has always been less popular with investigators than the first, and the available results still leave room for improvement, especially in connection with the "tilted" diagram.*

In what follows this problem is treated by a method which is believed to combine the accuracy with comparative simplicity of the final results—the latter, at least, to the extent which can reasonably be expected when dealing with an apparatus of such inherent complexity as the single-phase induction motor.

CONTENTS

Current Locus Diagram

The diagram will be based on the circuit of Fig. 1 which expresses the equivalence of the single-phase motor to two polyphase motors with primary windings connected in series.[1] The exciting impedance consists of a reactance X divided between the two stators; the core loss circuit g is connected across the line; no specific assumption is made as to the nature of the loss in an elliptical field, the current

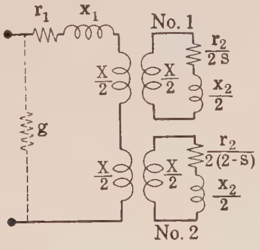

Fig. 1

covering this loss being always too small to have an appreciable influence on the phase relation and the magnitude of the vectors of the diagram.

In Fig. 2 let $O\,I$ be the current I' in the motor branch $r_1 - x_1 - X/2 - X/2$; the line voltage V' is the sum of $O\,R' = r_1\,I'$, $R'\,S' = x_1\,I'$, $S'\,M' = X/2\,I'$, $M'\,N' = X/2\,I'$, and of the e. m. fs. $M'\,P' = X/2\,I_2'$ and $N'\,Q' = X/2\,I_2''$ due to the reaction of the currents I_2' and I_2'' set up in the rotor circuits No. 1 and No. 2 by the e. m. fs. $S'\,M'$ and $M'\,N'$. Electromotive forces $M'\,P'$ and $N'\,Q'$ result from the diagram of Fig. 2 in which

$$S'\,F' = \frac{r_2\,I_2'}{2\,s}\,,\quad F'\,M' = \frac{X + x_2}{2}\,I_2'\,,$$

$$M'\,H' = \frac{r_2\,I_2''}{2\,(2 - s)}\,,\quad H'\,N' = \frac{X + x_2}{2}\,I_2''\,.$$

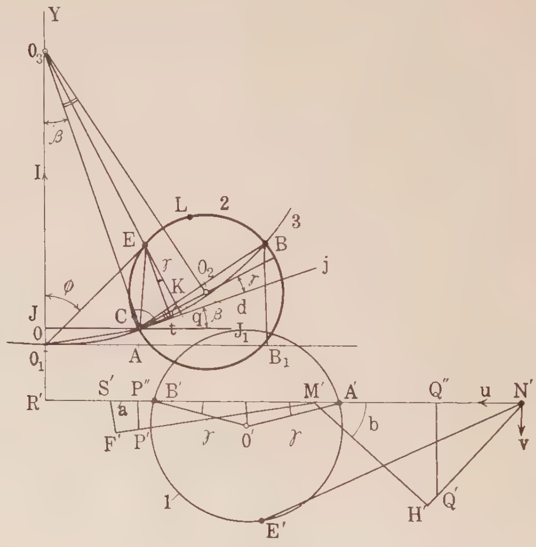

Fig. 2

Let
$$z_1^2 = \frac{r_2^2}{4\,s^2} + \left(\frac{X + x_2}{2}\right)^2$$

and
$$z_2^2 = \frac{r_2^2}{4\,(2 - s)^2} + \left(\frac{X + x_2}{2}\right)^2;$$

then (Fig. 2)
$$\sin a = \frac{X + x_2}{2\,z_1}\,,\quad \cos a = \frac{r_2}{2\,s\,z_1}\,,$$

1. The cross field theory leads to the same circuit. See V. Karapetoff, Journal A. I. E. E., August, 1921, p. 640. The primary and secondary windings are usually combined in a divided circuit instead of being left in inductive relation by means of 1 to 1 ratio transformers, as in Fig. 1.

To be presented by title only at the 10th Midwinter Convention of the A.I.E.E., New York, N.Y., February 15-17, 1922.

$$\sin b = \frac{X + x_2}{2\, z_2}, \cos b = \frac{r_2}{2\,(2 - s)\, z_2}.$$

If the current I' remains constant, the point N' is fixed, and the locus of the line voltage is described by the sum $N'\,E'$ of the vectors $M'\,P'$ and $N'\,Q'$. Let N' be the origin of coordinates u and v, with axes directed to the left and downwards, as shown; projections of $M'\,P'$ on these axes are:

$$M'\,P'' = M'\,P' \sin a = M'\,F' \frac{X}{X + x_2} \sin a$$

$$= S'\,M' \frac{X}{X + x_2} \sin^2 a = \frac{X}{2} \times \frac{X}{X + x_2} I' \sin^2 a;$$

and $M'\,P' \cos a = \frac{X}{2} \times \frac{X}{X + x_2} I' \sin a \times \cos a$

respectively; the e. m. f. $N'\,Q'$ gives for its projections similar expressions with the angle b instead of a; therefore, denoting

$$\frac{X^2\, I'}{2\,(X + x_2)} \text{ by } m,$$

the coordinates of E' are $u = m\,(\sin^2 a + \sin^2 b) = m\,(2 - \cos^2 a - \cos^2 b)$ and $v = m\,(\sin a \cos a + \sin b \cos b)$. The equation of the locus of E' is obtained by eliminating a and b between these expressions and the following relation:

$$\tan a + \tan b = \frac{(X + x_2)\, s}{r_2} + \frac{(X + x_2)\,(2 - s)}{r_2}$$

$$= \frac{2\,(X + x_2)}{r_2};$$

denoting $\frac{2\,(X + x_2)}{r_2}$ by n,

it is found: $u^2 + v^2 = m^2\,(4 + \cos^4 a + \cos^4 b - 4 \cos^2 a - 4 \cos^2 b + 2 \cos^2 a \cos^2 b + \sin^2 a \cos^2 a + \sin^2 b \cos^2 b + 2 \sin a \cos a \times \sin b \cos b) = m^2\,[4 - 3 \cos^2 a - 3 \cos^2 b + 2 \cos a \cos b \cos (a - b)\,] = m^2 \left[-2 + 3 \sin^2 a + 3 \sin^2 b + \frac{2 \sin (a + b) \cos (a - b)}{\tan a + \tan b} \right] = -2\, m^2 + 3\, m\, u + m^2/n\,(\sin 2\,a + \sin 2\,b) = -2\, m^2 + 3\, m\, u + \frac{2\, m}{n} v$, which can be written:

$$\left(u - \frac{3\, m}{2}\right)^2 + (v - m/n)^2 = m^2\,(1/4 + 1/n^2),$$

and shows that the locus is a circle 1 with the point O' of coordinates $u_0 = \frac{3\, m}{2}$, $v_0 = m/n$ as center. For $v = 0$ the equation gives $u = \frac{3\, m}{2} \pm m/2$, i. e. $N'\,A' = m$, $N'\,B' = 2\, m$. At B', $u = m\,(\sin^2 a + \sin^2 b) = 2\, m$, i. e. $\sin a = \sin b = 1$, which is possible only if $s = \infty$ at this point.

The current locus at constant voltage V is derived from the circle 1 by inversion with O as center and $V\,I'$ as constant of inversion, followed by the substitution for the inverse figure of its image with respect to $O\,Y$; this gives a circle 2 of center O_2. If the core loss is constant, the locus of the entire circuit of Fig. 1 is the circle 2 referred to an origin O_1 such that $O_1\,O$ = current in the branch g.

The inverse of the line $R'\,N'$ is a circle 3 of diameter $= \frac{V\,I'}{O\,R'} = \frac{V}{r_1}$, having its center O_3 on $O\,Y$; let γ be the angle which the radius $A\,O_2$ at A (corresponding to A') makes with the tangent $A\,j$ to the circle 3; this angle is equal to the angle $B'\,A'\,O'$; therefore,

$$\tan \gamma = v_0 : \frac{A'\,B'}{2} = \frac{2}{n} = \frac{r_2}{X + x_2} \tag{1}$$

Input to the Rotor[2]

At a point E of the circle 2 let $E\,q$ be $\perp$ to $A\,O_2$ and $E\,t \perp$ to $A\,j$; the triangles $O\,O_3\,E$ and $A\,O_3\,E$ having a common side $O_3\,E$ give $2\,A\,O_3 \times E\,t - A\,E^2 = 2\,O\,O_3 \times O\,E \times \cos \phi - O\,E^2 = \frac{V\,I \cos \phi}{r_1} - I^2$

$$= \frac{\text{rotor input}}{r_1}.$$

If R is the radius of the circle 2, then $A\,E^2 = 2\,R \times A\,d = 2\,R \times A\,q \cos \gamma$; the similar triangles $A\,O_3\,O_2$ and $A\,K\,q$ give $R \times A\,q = A\,O_3 \times K\,q$, hence,

$$\frac{\text{rotor input}}{r_1} = 2\,A\,O_3 \times E\,t - 2\,A\,O_3 \times K\,q \cos \gamma$$

$$= 2\,A\,O_3\,(E\,q \cos \gamma - K\,q \cos \gamma) = V/r_1 \times E\,K \cos \gamma, \text{ i. e.}$$

$$\textit{Rotor input} = E\,K \times V \cos \gamma \tag{2}$$

or, since γ is always very small:

$$\textit{Rotor input} = \sim E\,K \times V \tag{2a}$$

As will be seen, the graphical expressions of the performance elements are very simple in the constant current diagram (denoted "c. c. d."); they will be used for the derivation of the much less obvious relations in the constant voltage diagram ("c. v. d."). Since the current I' is arbitrary, it is convenient to simplify the figures by giving it such a value that the inverse of the circle 1 is equal to the circle 1 itself, which may then be considered both as the voltage locus at constant current, and—disregarding its incorrect location with respect to $O\,Y$—as the current locus

2. It is known that the primary and secondary outputs at a point E are proportional to the distances of E from the lines passing through the points of zero outputs (lines $A\,B$ and $C\,L$ in the figures). The purpose of the demonstration given below is to determine the coëfficients of proportionality in equations (2) and (3) and to establish equations (**2a**) and (**3a**) whose simplicity facilitates the use of the tilted diagram.

at constant voltage. Plain capitals A, B, etc., will refer to the points of the c. v. d.; the same capitals with an accent, A', B', etc., will be used for the corresponding points of the c. c. d.; two corresponding points of the circle, such as A and A' are on the same line passing through O. The voltage and the current will be denoted by V and I in the c. v. d., and by V' and I' in the c. c. d.; it is clear that at the corresponding points $V'/V = I'/I$.

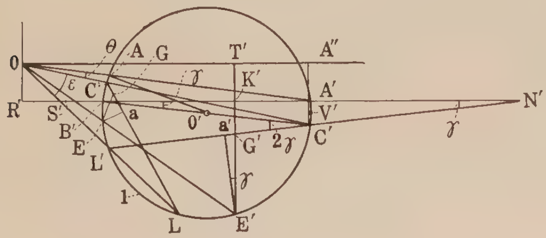

FIG. 3

In the triangles $M' F' S'$ and $M' P' P''$, Fig. 2, $M' P' \times M' F' = M' S' \times M' P''$; but $M' F' = \dfrac{X + x_2}{X} \times M' P'$, $M' P' = X/2\, I_2'$, and $M' S' = X/2\, I'$, therefore, $I_2'^2 = \dfrac{2I' \times M' P''}{X + x_2}$;

similarly, $I_2''^2 = \dfrac{2\, I' \times N' Q''}{X + x_2}$;

hence $r_2/2\,(I_2'^2 + I_2''^2)$ = rotor copper loss $= \dfrac{r_2\, I'}{X + x_2} \times u = I' u \tan \gamma$ (u = abscissa of E').

In Fig. 3 let $E' T'$ be ⊥ to $R' N'$, and $N' C' L'$ a line such that $\angle A' N' C' = \gamma$; then $G' K' = N' K' \tan \gamma = u \tan \gamma$, i. e. in the c. c. d. the rotor copper loss is $G' K' \times I'$. Since the input to the motor is $T' E' \times I'$, and the stator loss $= T' K' \times I'$, the rotor input is $K' E' \times I'$, and the rotor output $= G' E' \times I'$. At L' and C', $G' E' = O$; these points are the locked[3] and the no-load points (= zero — torque points) respectively. $A' C'$ is ⊥ to $R' N'$ because $B' A' = A' N'$; therefore, in the c. c. d. the rotor loss is the same at A' and C'; but at C' the stator supplies both its own loss $A' A'' \times I'$ and the rotor loss; at A' the latter must be supplied externally, as mechanical power. At synchronism (point U') $s = O$, $\cos a = O$, and v/u

$$= \frac{m \sin b \times \cos b}{m \sin^2 b} = \frac{r_2}{2\,(X + x_2)} = 1/2 \tan \gamma,$$

i. e. U' is the middle of the vertical segment (not shown) passing through U' and representing the rotor loss at U'; this expresses the well-known fact that at synchronous speed the stator supplies one-half of the rotor loss; the other half must be supplied externally.

3. This can also be proved by making $s = 1$ in the expressions of u and v, which gives $\dfrac{v}{u} = \dfrac{r_2}{X + x_2} = \tan \gamma$.

ROTOR OUTPUT

Let (Fig. 3) $E' a'$ be ⊥ to $C' L'$ and $E a$ ⊥ to $C L$; in Fig. 3a (giving details of Fig. 3) the inscribed triangles $C E L$ and $C' E' L'$ give:

$$\frac{E' a'}{E a} = \frac{E' C' \times E' L'}{E C \times E L}; \text{ but } \frac{E' C'}{E C} = \frac{O E'}{O C};$$

$$\frac{E' L'}{E L} = \frac{O L'}{O E}; \text{ and } \frac{O L'}{O C} = \frac{L' C'}{L C};$$

$$\text{hence } \frac{E' a'}{E a} = \frac{O E'}{O E} \times \frac{L' C'}{L C} = \frac{V'}{I} \times \frac{L' C'}{L C}.$$

The rotor output at E' is

$$E' G' \times I' = \frac{E' a' \times I'}{\cos \gamma};$$

therefore, the rotor output at E in the c. v. d. is

$$\left(\frac{E' a' \times I'}{\cos \gamma}\right) \times \left(\frac{V}{V'}\right)^2 = \frac{E a \times V}{\cos \gamma} \times \frac{L' C'}{L C}.$$

In Fig. 3 let $\epsilon = \angle C O L$; the arc $B' E L'$ is measured by 4γ; the arc $L' E' C' = B' E' C' - B' E L' = \pi - 4\gamma$; therefore, the arc $C E L$ = arc $C L'$ + arc $L' L = (C' E' L - 2\epsilon) + (L' E' C' - C' E' L) = -2\epsilon + L' E' C' = \pi - 4\gamma - 2\epsilon$;

$$\text{hence, } \frac{L' C'}{L C} = \frac{\sin^1/_2\,(\pi - 4\gamma)}{\sin^1/_2\,(\pi - 4\gamma - 2\epsilon)}$$

$$= \frac{\cos 2\gamma}{\cos(\epsilon + 2\gamma)}.$$

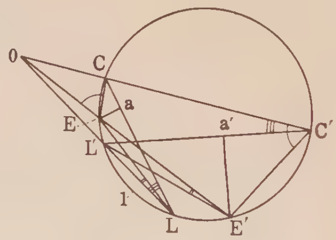

FIG. 3A

Let $\theta = \angle A O C$; the arc $A' C' = 2\gamma$, therefore, the arc $A C = 2\gamma - 2\theta$. The angle which $C L$ makes with the diameter $A O'$ is

$$\frac{\pi - \text{arc } A C L}{2} - \frac{\text{arc } A C}{2} = \frac{\pi - \text{arc } C E L}{2}$$

$$- \text{arc } A C = \frac{\pi - (\pi - 4\gamma - 2\epsilon)}{2} - (2\gamma - 2\theta)$$

$$= \epsilon + 2\theta;$$

if $E G$ is drawn ⊥ to $A O'$, then $E a = E G \times \cos(\epsilon + 2\theta)$; substituting:

$$\textit{Rotor output} = E G \times V \times \frac{\cos 2\gamma}{\cos \gamma} \times \frac{\cos(\epsilon + 2\theta)}{\cos(\epsilon + 2\gamma)} \qquad (3)$$

The angles θ and γ are very small; moreover, θ

differs from γ only by one = half of the negligibly small arc $A\,C$; both fractions in (3) are very close to unity (and differ from it in the opposite senses), therefore,

$$\textit{Rotor output} = \sim E\,G \times V \tag{3a}$$

If the rotor resistance is very high, it may be advisable to measure γ, ϵ and θ on the diagram and use equation (3), but this is seldom necessary.

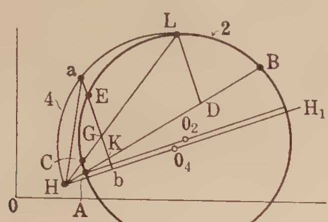

Fig. 4

Rotor Copper Loss

When equations (**2a**) and (**3a**) are applicable,[4] they give (Fig. 4)

$$\textit{Rotor copper loss} = E\,K \times V - E\,G \times V$$
$$= G\,K \times V \tag{4a}$$

In Fig. 4 let H be the intersection of $L\,C$ with $B\,A$, and 4 = a circle through H and L, with its center O_4 on $H\,H_1$ parallel to $A\,O_2$. Since $G\,K$ is proportional to $H\,b$ and therefore proportional to $H\,a^2$, the rotor loss $G\,K \times V$ is proportional to $H\,a^2$. Let $L\,D$ be $\perp$

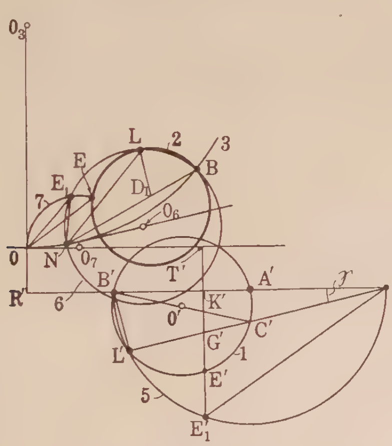

Fig. 4A

to $A\,O_2$; at L the rotor loss = rotor input = $\sim L\,D \times V$; therefore, the coefficient of proportionality is

$$V \times \frac{L\,D}{H\,L^2}:$$

$$\textit{Rotor copper loss} = \sim H\,a^2 \times \left(V \times \frac{L\,D}{H\,L^2} \right) \tag{4b}$$

Expressions (2a), (3a) and (4a) show that *if representative segments of the rotor input, output and loss are drawn perpendicular to the diameter passing through the point of zero stator output, they can be read directly in amperes, as in the current locus of a polyphase motor.*[5] The expressions are, however, only approximate in the single-phase motor, although the accuracy is sufficient in most cases occurring in practise.

Speed

Let $a\,a$ (c. v. d. in Fig. 5) be an arbitrary line parallel to the tangent at B ($s = \infty$), and f, g, h, the points of intersection of this line with $B\,L$, $B\,E$ and $B\,U$ respectively (U = point of synchronous speed); then, if S is the speed with synchronism as unity:

$$S = \frac{f\,g}{f\,h} \tag{5}$$

This expression is well-known; a brief outline of its derivation will be sufficient. In the c. c. d. of Fig. 5 let f' be the intersection of $B'\,L'$ and $A'\,C'$ produced; using the same axes of coordinates u, v, (to the left and downwards from N') as in Fig. 2, let p and q be coordinates of a point E'; the equation of $N'\,f'$ is $v = u$

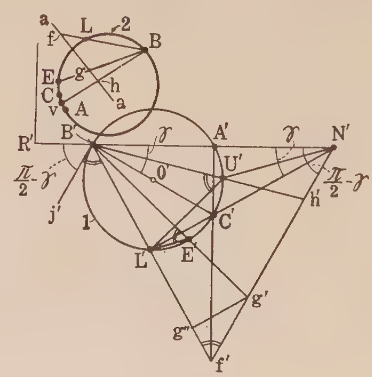

Fig. 5

$\times \cot \gamma$; the equation of $B'\,E'$ is $q\,(u - 2\,m) = v\,(p - 2\,m)$; these equations give for the coordinates u_1 and v_1 of g':

$$u_1 = \frac{2\,m\,q \tan \gamma}{q \tan \gamma + 2\,m - p},$$

$$v_1 = \frac{2\,m\,q}{q \tan \gamma + 2\,m - p}.$$

The equation of $B'\,f'$ is $u + v \times \tan \gamma - 2\,m = O$; therefore, the distance $g''\,g'$ of g' from $B'\,f'$ is proportional to $u_1 + v_1 \tan \gamma - 2\,m$; but, in connection with Fig. 2 it was found: $p = m\,(\sin^2 a + \sin^2 b)$; $q = m\,(\sin a \cos a + \sin b \cos b)$ hence, substituting, $g''\,g'$ is proportional to

$$\frac{\tan \gamma\,(\sin a \cos a + \sin b \cos b) - \cos^2 a - \cos^2 b}{\tan \gamma\,(\sin a \cos a + \sin b \cos b) \quad + \cos^2 a + \cos^2 b}$$

substituting for $\tan \gamma$, $\sin a$, etc. their expressions as functions of the slip and the constants of the motor gives, after some transformations: $g''\,g'$ is proportional to $(1 - s)^2$ and to S^2; therefore, $f'\,g'$ is proportional to S^2, and, if U' is the point of synchronous speed,

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4. See Appendix 1 for the exact expression of the rotor copper loss.

5. Journal A. I. E. E., April 1921, p. 329.

$$S^2 = \frac{f'\,g'}{f'\,h'}\,.$$

It can easily be seen that $N'\,f'$ is parallel to the tangent $B'\,j'$ at B'; the triangles $B'\,L'\,E'$ and $B'\,L'\,U'$ are, therefore, similar to $B'\,f'\,g'$ and $B'\,f'\,h'$ respectively; hence, $\dfrac{f'\,g'}{L'\,E'} = \dfrac{B'\,f'}{B'\,E'}$ and $\dfrac{f'\,h'}{L'\,U'} = \dfrac{B'\,f'}{B'\,U'}$,

which gives
$$\frac{f'\,g'}{f'\,h'} = \frac{L'\,E'}{L'\,U'} \times \frac{B'\,U'}{B'\,E'}\,.$$

It is, generally, $L'\,E' = L\,E$

$$\times \frac{\text{constant of inversion between c. c. d. and c. v. d.}}{O\,L \times O\,E}\,,$$

and similar relations for $L'\,U'$, $B'\,U'$, and $B'\,E'$; substitution shows that

$$\frac{L'\,E'}{L'\,U'} \times \frac{B'\,U'}{B'\,E'} = \frac{L\,E}{L\,U} \times \frac{B\,U}{B\,E}\,;$$

but
$$\frac{L\,E}{L\,U} \times \frac{B\,U}{B\,E} = \frac{f\,g}{f\,h}\,,$$

therefore,
$$\frac{f\,g}{f\,h} = \frac{f'\,g'}{f'\,h'} = S^2\,.$$

It was found that

$$\tan \angle\, A'\,N'\,U' = 1/2 \tan \angle\, A'\,N'\,C',$$

i. e. U' is nearly equidistant from A' and C'; since $A'\,C'$ is $\perp$ to $B'\,N'$ and far from the center of inversion the point U in the c. v. d. is nearly equidistant from A and C, and can be located by the eye. Usually, however, the no-load point C can be used instead of U; eq. (5) gives then the speed with the no-load speed as unity.

Torque

The torque in synchronous watts is

$$= \frac{\text{rotor output}}{S} = \frac{E\,G \times V}{S}\,.$$

The following approximate expression can also be used; it can be shown that S^2 is approximately equal to the efficiency of the rotor:[6]

$$S^2 = \sim \frac{E\,G}{E\,K} \text{ (Fig. 4)} \qquad \textbf{(5a)}$$

Therefore, approximately:

$$\textit{Torque in synchronous watts} = \frac{E\,G \times V}{S}$$

$$= V \sqrt{E\,G \times E\,K}$$

$$= \sqrt{(\textit{rotor output})\,(\textit{rotor input})} \qquad \textbf{(6a)}$$

It remains now to establish a few analytical relations useful for the construction of the locus from the test data. The branch $r_1 - x_1 - X$ of the circuit of Fig. 1 is equivalent to an impedance whose elements can conveniently be determined from the c. c. d. of Figs. 2 and 3 by observing that a point E' of coordinates u and v the equivalent resistance is

$$\frac{E'\,T'}{I'} = r_1 + \frac{v}{I'}\,,$$

and the equivalent reactance

$$= \frac{R'\,K'}{I'} = x_1 + \frac{S'\,N' - u}{I'} = x_1 + X - u/I'\,.$$

Substituting for u and v their values as functions of $\sin a$, $\sin b$ etc. and denoting $1 + x_2/X$ by k (with $k = \sim 1$), it is found:

At the locked point L', $s = 1$:

Equivalent resistance $= r_1$

$$+ \frac{r_2}{k^2 + (r_2/X)^2} = \sim r_1 + r_2/k^2 \qquad \textbf{(7)}$$

Equivalent reactance $= x_1$

$$+ \frac{X\,[r_2^2 + x_2\,(X + x_2)]}{r_2^2 + (X + x_2)^2}$$

$$= x_1 + \frac{x_2 + \dfrac{r_2^2}{(X+x_2)}}{k + \dfrac{r_2^2}{X\,(X + x_2)}} = \sim x_1 + x_2/k \qquad \textbf{(8)}$$

At the no-load point C':

Equivalent resistance $= r_1 + \dfrac{r_2}{2\,k^2}$ **(9)**

Equivalent reactance $= x_1 + X - \dfrac{X^2}{2\,(X + x_2)}$

$$= x_1 + X\,\frac{2\,k - 1}{2\,k} \qquad \textbf{(10)}$$

At the point A': **(11)**

Equivalent resistance $= r_1$

Equivalent reactance $= x_1 + X\,\dfrac{2\,k - 1}{2\,k}$ **(12)**

At the point B' ($s = \propto$);

Equivalent resistance $= r_1$ **(13)**

Equivalent reactance $= x_1 + X - \dfrac{X^2}{X + x_2}$

$$= x_1 + x_2/k \qquad \textbf{(14)}$$

Construction of the Diagram from Test Data

The necessary tests are: 1. Resistance r_1; 2. Locked point L: I_s amperes, W_s watts, $\cos\phi_s$ = power factor; 3. No-load point C: I_0 ampere, W_0 watts. The open rotor circuit point test should also be made, whenever possible (slip ring motors, repulsion-induction motors).[7] One of the difficulties of the problem is the fact that the point A is not given by the test; in the majority of methods of constructing the diagram

6. A. S. McAllister, "Simple Circle Diagram of the Single-Phase Induction Motor" *Electrical World*, June 30, 1906. See also Appendix 2.

7. The no-load test point corresponds to a small friction torque; experience shows that a correction for this torque, theoretically simple, is not necessary.

A is considered as coinciding with C; when this is permissible, as in large motors, it greatly simplifies the construction; but in small motors the arc $A\,C$ is not always negligible, and it is necessary to find the point A, which involves certain complications.

The small chord $A\,C$, Fig. 2, is nearly $\perp$ to the diameter $A\,O_2$ and (equation **4a**) nearly equal to

$$\frac{\text{rotor loss at } C}{V};$$

moreover, with γ very small, $A\,C$ nearly coincides in direction with $O_3\,A$; therefore,

$$O_3\,C = \sim O_3\,A - \frac{\text{rotor loss at } C}{V} = \frac{V}{2\,r_1} - I_0^2 \times \frac{r_2}{2\,k^2} \times \frac{1}{V},$$

(equation **9**); equation (**7**) shows that

$$\frac{r_2}{k^2} = \frac{W_s}{I_s^2} - r_1;$$

with this value $O_3\,C$ can be calculated and O_3 located on $O\,Y$; the circle 3 of radius $\frac{V}{2\,r_1}$ is then drawn and determines the points O and A, the latter as the intersection of the circle 3 with $O_3\,C$ produced (or, more accurately, with the inverse of $A'\,C'$, *i. e.* with a circle passing through O and C and having its center on the line $O\,B_1 \perp$ to $O\,Y$).

The next step is to calculate the angle γ; it is always so small that the following method is sufficiently accurate: x_1 and x_2 are calculated from equation (**8**) which gives: $x_1 + x_2/k = \sim (x_1 + x_2) = V/I_s \times \sin\phi_s$; it may be assumed that $x_1 = \sim 0.6$ to 0.7 of $(x_1 + x_2)$; X is calculated from equation (**10**) as follows:[8]

$$x_1 + X\,\frac{2\,k - 1}{2\,k} = \sim x_1 + X/2 = V/I_0\,;$$

equation (**7**) gives r_2/k^2 as above; with these data

$$\tan\gamma = \frac{r_2}{X + x_2} = r_2/k^2 \times \frac{X + x_2}{X^2}$$

can be calculated. The center O_2 of the locus is the intersection of the perpendicular bisector of $C\,L$ with a line passing through A and making an angle $90 - \gamma$ with $O_3\,A$. As a check, it will be found that the point A found above is either on the locus or at a negligible distance from it.

If the object of the test is the determination of the constants of the motor, more accurate values of $x_1 + x_2/k$ and X can be found from the diagram as follows: If $\phi\,\infty$ is the angle of lag at B, then equations (**13**) and (**14**) give:

$$x_1 + x_2/k = r_1 \tan\phi\,\infty = r_1 \times \frac{O\,B_1}{B\,B_1} \qquad (\mathbf{15})$$

On the basis of equation (**11**) and (**12**) X is calculated from the equation

$$\left(x_1 + X\,\frac{2\,k-1}{2\,k}\right)^2 + r_1^2 = \left(\frac{V}{O\,A}\right)^2 \qquad (\mathbf{16})$$

with k calculated with the previously found preliminary value of X.

If it is desired to calculate the rotor loss by the exact method (App. 1), the point N on the circle 3 can be located by observing that

$$O\,N = \frac{V}{\sqrt{r_1^2 + (X + x_1)^2}} = \sim \frac{V}{X + x_1}.$$

If O_3 is at an inconveniently great distance from the locus, the necessity of drawing the circle 3 can be avoided as follows: The angle β (Fig. 2) of the horizontal $A\,J$ with the tangent $A\,j$ to the circle 3 is given by

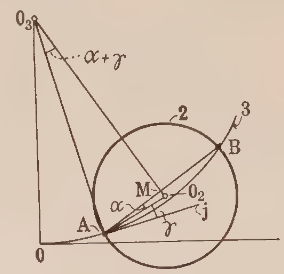

FIG. 6

$$\sin\beta = \frac{A\,J}{A\,O_3} = \sim \frac{2\,r_1\,I_0}{V}.$$

$A\,C$ is nearly $\perp$ to the diameter $A\,O_2$, which makes an angle γ with $A\,j$, i. e. $A\,C$ makes an angle $= \sim \beta + \gamma$ with $O\,Y$; γ is calculated as shown above; the direction and length of

$$A\,C = \sim I_0^2\,\frac{r_2}{2\,k^2\,V}$$

determine the point A and the locus 2. It can easily be seen that

$$\angle\,J\,A\,O = \frac{\angle\,A\,O_3\,J}{2} = \beta/2,$$

i. e. the point O is the intersection of $O\,Y$ with the bisector of the angle $J_1\,A\,j$; this bisector can be drawn by the eye. Finally, the point B ($s = \infty$) is determined by the angle $O_2\,A\,B$ as follows: In Fig. 6 let R be the radius of the locus and $A\,j$ = the tangent to the circle 3; then,

$$\sin\angle\,A\,O_3\,M = \sin(\alpha + \gamma) = \frac{A\,M}{A\,O_3} = \frac{R\cos\alpha \times 2\,r_1}{V};$$

8. If the open rotor circuit test is available, it gives directly $x_1 + x = \sim \frac{V}{\text{current}}$ it may be observed, however, that this test, made with the rotor at rest, cannot be considered as giving the point N and used for the determination of the circle 3, because, unlike N, it does not correspond to the same conditions of the core loss and friction as the point C.

hence, developing,

$$\tan \alpha = \frac{2\, r_1 R}{V \cos \gamma} - \tan \gamma = \sim \frac{2\, r_1 R}{V} - \tan \gamma \quad (17)$$

Fig. 7 gives an example of the diagram applied to a 1/4-h. p., four-pole, 60-cycle motor. Resistance $r_1 = 6.8$ ohms; no-load test: 220 volts, 2.04 amperes, 116 watts; locked test: 220 volts, 8.46 amperes, 1300 watts. For this motor $\gamma = 3$ deg. 37 min., $\epsilon = 36$ deg. 33 min., $\theta = 3$ deg. 6 min. The coefficients in equations (2) and (3) are 0.998 and 1.011 respectively. Brake test points are shown in the diagram.

Appendix I

In Fig. 4A let 5 be a circle described on $B' N'$ as diameter. This circle is the voltage locus of a polyphase motor of exciting reactance X and of constants r_1, x_1, r_2, x_2;[9] it passes through L' because $\angle\, B' L' C' = \pi/2$. At a point E_1' the rotor current is $\frac{N' E_1'}{X}$,

and the rotor loss

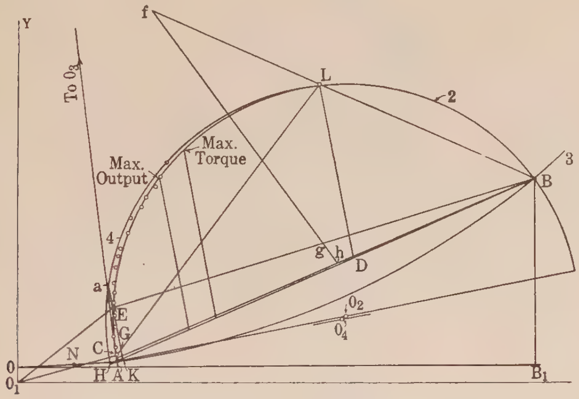

Fig. 7

$$= \frac{N' E_1'^2}{X^2} \times r_2 = \frac{N' B' \times N' K' \times r_2}{X^2}$$

$$= \frac{X^2 I'}{X + x_2} \times \frac{K' G' \times \cot \gamma \times r_2}{X^2} = K' G' \times I',$$

i. e. the same as for the single-phase motor at E'. The current locus corresponding to 5 is a circle 6 of center O_6 passing through N, L and B and normal to the circle 3 at N,[9] the points E_1 and E lie on the inverse of the line $E_1' E'$, i. e. on a circle 7 passing through O and having its center O_7 on $O\,T'$. Since E_1' and E' correspond to different voltages $O\,E_1'$ and $O\,E'$, the rotor losses in the c. v. d. are in the ratio

$$\left(\frac{O\,E_1'}{O\,E'}\right)^2 = \left(\frac{O\,E}{O\,E_1}\right)^2.$$

The polyphase motor rotor loss is proportional to $N\,E_1^2$, therefore, the single-phase motor loss is proportional to

$$N\,E_1^2 \times \left(\frac{O\,E}{O\,E_1}\right)^2,$$

and the coefficient of proportionality is found by reference to the point L where the loss is[9] $D_1\,L \times V$ (with $D_1\,L \perp$ to $N\,O_6$) which gives

$$\textit{Rotor copper loss} = O\,E^2 \times \left(\frac{N\,E_1}{O\,E_1}\right)^2 \times V \times \frac{D_1\,L}{N\,L^2} \quad (4)$$

Appendix II

At a point E' (Fig. 3) of coordinates u and v, the rotor input $= E' K' \times I' = v \times I'$; the rotor output $= (E'K' - G' K')\, I' = (v - u \tan \gamma)\, I'$; rotor efficiency

$$= \frac{v - u \tan \gamma}{v}$$

$$= \frac{\sin a \times \cos a + \sin b \times \cos b - (\sin^2 a + \sin^2 b) \tan \gamma}{\sin a \times \cos a + \sin b \times \cos b};$$

substituting for sin a etc. their values and transforming, it is found:

$$\textit{Rotor efficiency} = (1 - s)^2 \times \frac{2\, s - s^2 - \tan^2 \gamma}{2\, s - s^2 + \tan^2 \gamma} \quad \mathbf{(5b)}$$

If $\tan^2 \gamma$ is small relative to $2\, s - s^2$, as at the point of maximum torque, then

Rotor efficiency $= \sim (1 - s)^2 = \sim S^2$.

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9. See Journal A. I. E. E., April, 1921, pp. 326-332.

TELEGRAPH AND TELEPHONE NOTES

On November 25, a conference was held in the Engineering Societies Building, New York, attended by representatives from the commercial radio companies, on which occasion Dr. Dellinger, of the Bureau of Standards, Washington, submitted a report of the deliberations of the Technical Committee which met in Paris during the past summer. This committee was named by the Government to consider questions of international communication.

Fulton Cutting, New York, has been nominated for the office of President, Institute of Radio Engineers, for the year 1922. Brig. Gen. Edgar Russel, who also was nominated, withdrew on account of being transferred from New York. For the office of vice-president E. L. Chaffee, of Harvard University, and Lloyd Espenschied, of the American Telephone and Telegraph Company, New York, are the nominees.

On the evening of November 30, a successful demonstration of radio telephony between New York and Pittsburgh was made by engineers of the Western Electric Company. The matter sent out consisted of a number of speeches by prominent engineers and of musical selections. The quality of the transmission on this occasion showed marked improvement over previous trials—the matter sent out was clearly heard in all parts of the eastern and mid-western states. In the transmitting circuit two tubes only were employed.

Heat Losses in Stranded Armature Conductors

BY WALDO V. LYON

Associate, A. I. E. E.

Assistant Professor of Electrical Engineering, Massachusetts Institute of Technology.

In the present paper, which is a continuation of one presented at the last annual convention, the author extends the method of complex hyperbolic functions to the solution of the problem of heat losses in stranded conductors embedded in rectangular slots. In the preceding paper the discussion was confined to solid conductors and to those having an infinite number of strands. In the latter case, the insulation between the strands was assumed to have no appreciable thickness. In the present paper, conductors are considered which have a finite number of strands separated by insulation of appreciable thickness. In the mathematical development which is to follow, free use is made of the results obtained in the first paper.

THE first step in the solution of the problem of heat losses in stranded armature conductors is to obtain an expression showing the relation between the currents in adjacent strands. If two strands are adjacent at any point, they are adjacent throughout their length. If the conductor is turned over in the end connection, the strand b, which is above a in one coil side, is below a in the next coil side, Fig. 1. The difference in pressure per half turn between these two strands is that between the lowest element of b and the highest element of a. If the conductor is turned over in the end connection, in the next half turn, this difference is between the lowest element of a and the highest element of b. The difference in pressure in each of these is cases given in equations (**6d**) and (**6r**). By the proper substitution, these equations can be written in terms of the currents in the adjacent strands and the current in the slot below them. See equations (**7a**) and (**7b**). These two equations are similar in form. Between the points at which the strands are joined together, the sum of all of these half-turn differences in pressure must be zero. This equation, (**8**), may be written in following form:

$$(I_{q(p+1)} - I_{qp}) - \frac{\left(\alpha a + 2\tanh\frac{\alpha d}{2m}\right)\frac{\alpha d}{m}}{\dfrac{\frac{\alpha d}{m}}{\sinh\frac{\alpha d}{m}} + \dfrac{l_2}{l_1}}\left(I_0 + \sum_1^p I_{qp}\right) = 0;$$

where α is calculated for the embedded portion of the winding. Compare this with the fundamental equation (**1**) in the preceding paper which for the case of infinitesimal strands may be written in the following form:

$$w\,dx\,d\underset{\cdot}{c} - \frac{\alpha^2 (dx)^2}{1 + \frac{l_2}{l_1}}\left(I_0 + \int_0^x w\,\underset{\cdot}{c}\,dx\right) = 0;$$

where α is also calculated for the embedded portion of the winding only, and l_1 and l_2 are respectively the length of the armature core and the length of an end turn. Notice that these equations are similar. The first term in each is the vector difference between the currents in adjacent strands. The coefficients of the second terms are the same when the number of strands, m, increases without limit and there is no insulating space, a, between them. It is further shown that the vector constants, I_0, are identical in the two equations. This similarity suggests that the currents in the strands of the stranded conductor may be equal to those in corresponding divisions of a solid conductor of the same depth. In the latter case, the imaginary strands would of course not be separated. (Fig. 2.)

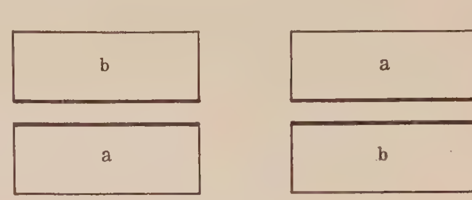

FIG. 1

Such proves to be the case provided the hyperbolic angular depth, $\beta\, d$, of the solid conductor has a certain value. This value is determined by the relation (Equation **10a**):

FIG. 2

$$\sinh^2\frac{\beta d}{2m} = \frac{\frac{\alpha d}{2m}\left(\frac{\alpha a}{2} + \tanh\frac{\alpha d}{2m}\right)}{\dfrac{\frac{\alpha d}{m}}{\sinh\frac{\alpha d}{m}} + \dfrac{l_2}{l_1}}$$

Were it not for this relation between the currents in the two cases the completion of the solution would be much more difficult. The reason is that the current

To be presented by title only at the 10th Midwinter Convention of the A. I. E. E., New York, N. Y., February 15-17, 1922.

up to any strand in the stranded conductor must be determined by a summation of vector quantities whereas in a solid conductor the current up to any point may be obtained by integration, a much simpler process. The current in any strand may also be obtained by integration between the proper limits.

This equality of the currents in a stranded conductor and a solid one recalls the equality of currents and of voltages that exists in an artificial transmission line and a smooth line when there is a certain relation between their constants.

We are now in a position to determine the expressions for the resistance drop in either the top or bottom strand of a conductor. It is only in the case of strands of infinitesimal thickness that the expressions are the same. Compare equations (**13b**) and (**14b**) with equation (**7**) in the preceding paper. They are identical except that M and N in the preceding paper are replaced by similar functions, M' and N' and that there are terms involving T' and S' which would disappear if the number of strands, m, were infinite and there were no insulating space, a, between them. We must also derive expressions for the pressure acting in conductors below a given one due to flux within the latter. These expressions are given in equations (**15b**) and (**16b**). These expressions are identical with the corresponding ones for solid or finely laminated conductors except that N' replaces N, that T' replaces $\alpha^2 d^2$ to which it reduces if there are an infinite number of laminations with no space between them, and that there is an added term involving S', a pure imaginary, which depends upon the insulating space between the laminations.

Having determined these four pressure equations, the determination of the heating loss or of the leakage impedance follows precisely the same procedure that was used in the preceding paper.

The author wishes to point out again a fact which he believes is not generally appreciated. A finely stranded conductor with the strands continuous throughout the whole coil will have a resistance ratio equal to that of a single finely stranded half turn of one half its depth, provided the coil has an even number of turns and the end connections are turned over on *one side only*. For conductors up to about one inch in depth, the alternating-current resistance is then but 1 or 2 per cent greater than the direct-current resistance.

Mathematical Analysis

The description of windings considered follows. The embedded portions of the winding are in open reactangular slots; there are two coil sides per slot; the pitch is either full or fractional; each coil side has n layers or conductors, and each layer has m laminations or strands; the strands occupy the same relative positions throughout the embedded portion of any half turn; the strands are arranged one above the other and have equal rectangular cross-sections; the strands are separated by insulation of uniform thickness; when the conductors are turned over or twisted in the end connections it is done in such a manner that any strand occupies the same relative position with respect to the bottom of the conductor of which it is a part that it does with respect to the top of the successive half turn; the coil as a whole is not turned over in the end connection; strands of any conductor may be joined at the beginning and end of a half turn, a full turn, or of a complete coil; the end connections may be turned over on neither side, on one side, or on both sides.

The strands are designated by the subscripts $q\,p$. The $q\,p$ strand is the p strand of the q conductor. The number of the strand may be counted from the bottom of the conductor of which it is a part, in which case the order of the strands is said to be direct, or from the top of the conductor of which it is a part, in which case the order of the strands is said to be reverse. Thus in a winding whose strands are continuous throughout a whole coil and whose end connnections are turned over on both sides the strands are in the direct order in one coil side and in the reverse order in the other coil side of the same coil. The number of the conductor is always counted from the bottom of the coil side of which it is a part.

The armature currents are assumed to be balanced. In the end connections the r. m. s. current density throughout any strand is assumed to be constant. In the embedded portion of the coil the r. m. s. current density in any strand is variable. This vector r. m. s. current density in the embedded portion of the $q\,p$ strand is:

$$\underset{\cdot}{c}_{qp} = \frac{m}{w\,d}\left(I_{qp}\,\frac{\alpha\,d}{m}\;\frac{\cosh\alpha\,x}{\sinh\dfrac{\alpha\,d}{m}} - I_{b\,qp}\,\frac{\alpha\,d}{m}\tanh\frac{\alpha\,d}{2m}\cosh\alpha\,x + I_{b\,qp}\,\frac{\alpha\,d}{m}\sinh\alpha\,x\right)^{1} \qquad (\mathbf{1})$$

$\underset{\cdot}{c}$ is the vector r. m. s. current density at points x centimeters from the bottom of the $p\,q$ strand; d is the net depth[2] of the conductor; d/m is the depth of one strand; w is the width of the conductor or strand; I_{qp} is the current in the $q\,p$ strand; $I_{b\,qp}$ is *all* of the current in the slot *below* the $q\,p$ strand;

$$\alpha^2 = j\,\frac{8\,\pi^2\,w\,f}{\rho\,s};$$

1. See: Heat Losses in the Conductors of Alternating-Current Machines presented at Annual Convention A. I. E. E., June 1921. (Equation (4). For solid conductors like the $q\,p$ strand I_o is all of the current in the slot below the conductor considered.)

2. The net depth of the conductor is the depth it would have if the insulation between the strands were of zero thickness.

where f is the frequency, w, the width of the conductor, and s, that of the slot, and ρ is the resistivity of the material of the conductor at the working temperature. ρ is assumed the same for every strand.

The current densities at the bottom, center and top of the $q\,p$ strand are respectively $c_{q_p b}$, $c_{q_p c}$ and $c_{q_p t}$. Substitution in equation (1) shows that

Since $x = O$,

$$c_{q_p b} = \frac{m}{w\,d}\left(I_{q_p} \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} - I_{b\,q_p} \frac{\alpha\,d}{m} \tanh \frac{\alpha\,d}{2\,m} \right) \quad (2)$$

$$\text{Since } x = \frac{d}{2\,m},\; c_{q_p c} = \frac{m}{w\,d}\, I_{q_p} \frac{\frac{\alpha\,d}{2\,m}}{\sinh \frac{\alpha\,d}{2\,m}} \quad (3)$$

$$\text{Since } x = \frac{d}{m},\; c_{q_p t} = \frac{m}{w\,d}\left(I_{q_p} \frac{\alpha\,d}{m} \coth \frac{\alpha\,d}{m} + I_{b\,q_p} \frac{\alpha\,d}{m} \tanh \frac{\alpha\,d}{2\,m} \right) \quad (4)$$

or

$$c_{q_p t} = \frac{m}{w\,d} \left\{ I_{q_p} \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + I_{b\,q\,(p+1)} \frac{\alpha\,d}{m} \tanh \frac{\alpha\,d}{2\,m} \right\} \quad (4a)$$

It is shown in the paper already referred to that the flux, ϕ_{q_p}, within the embedded portion of any solid conductor, the q_p strand for example, due to current within the conductor, I_{q_p} for example, and to all of the current in the slot below it, which in this case is $I_{b\,q_p}$, is

$$\phi_{q_p} = \frac{1}{j\,\omega} \frac{l_1\,\rho\,m}{w\,d} \left(I_{q_p} + 2 I_{b\,q_p} \right) \frac{\alpha\,d}{m} \tanh \frac{\alpha\,d}{2\,m} \quad (5)$$

where l_1 is the length of the armature core. The flux, ϕ_a, between the $q\,(p+1)$ and the $q\,p$ strands is

$$\frac{4\,\pi\,l_1\,a}{s} I_{b\,q\,(p+1)},$$

which may be written in a form similar to equation (5). a is the thickness of the insulation between the strands

$$\phi_a = \frac{1}{j\,\omega} \frac{l_1\,\rho\,m}{w\,d} \left(I_{q_p} + I_{b\,q_p} \right) \frac{\alpha\,d}{m} \cdot \alpha\,a \quad (5a)$$

The proper combination of these five equations, *viz.*, (2), (3), (4), (5) and (5a) will give the heat loss in any of the types of stranded conductors we are considering. The leakage reactance due to flux within the embedded portion of the conductor may also be found.

Relation between the Currents in Adjacent Strands of the Same Conductor

For strands numbered in the direct order, the difference in pressure between adjacent elements of adjacent strands is the difference in pressure between that in the topmost element of the p strand and the bottom element of the $(p+1)$ strand of the same conductor. For strands numbered in the reverse order this same difference is that between the pressures in the lowest element of the p strand and in the topmost element of the $(p+1)$ strand. The total difference in pressure between these adjacent elements must be zero between the points at which the strands are joined.

For strands numbered in the direct order this difference in pressure, D_d, for a half turn is

$$D_d = \left(l_1\,\rho\,c_{q\,(p+1)\,b} + l_2 \frac{\rho\,m}{w\,d} I_{q\,(p+1)} \right) - \left(l_1\,\rho\,c_{q_p t} + l_2\,\rho \frac{m}{w\,d} I_{q_p} + l_1 \frac{\rho\,m}{w\,d} I_{b\,q\,(p+1)} \frac{\alpha\,d}{m} \cdot \alpha\,a \right) \quad (6d)$$

l_1 and l_2 are respectively the lengths of the armature core and of the end connections for a half turn. The second term in each parenthesis is the resistance drop in the end connections. The third term in the second parenthesis is the drop in pressure in the $q\,p$ strand due to the flux ϕ_a. The reactance drop in the end connections due to internal leakage flux is neglected, *i. e.*, the current density is assumed to be uniform in each strand of the end connections.

Substitute equations (2) and (4) in equation **(6d)**

$$D_d = \frac{m}{w\,d}\,\rho \left\{ \left[l_1 I_{q\,(p+1)} \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} - l_1 I_{b\,q\,(p+1)} \frac{\alpha\,d}{m} \left(\alpha\,a + \tanh \frac{\alpha\,d}{2\,m} \right) + l_2 I_{q\,(p+1)} \right] - \left[l_1 I_{q_p} \frac{\alpha\,d}{m} \coth \frac{\alpha\,d}{m} + l_1 I_{b\,q_p} \frac{\alpha\,d}{m} \tanh \frac{\alpha\,d}{2\,m} + l_2 I_{q_p} \right] \right\}$$

but $\quad I_{b\,q_p} = I_{b\,q\,(p+1)} - I_{q_p}$

Thus:

$$D_d = \frac{m}{w\,d}\,\rho \left\{ \left(l_1 \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + l_2 \right) \left(I_{q\,(p+1)} - I_{q_p} \right) - l_1 I_{b\,q\,(p+1)} \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \right\} \quad (6a)$$

For strands numbered in the reverse order the pressure difference, D_r, for a half turn is:

$$D_r = \left(l_1\,\rho\,c_{q\,(p+1)\,t} + l_2\,\rho \frac{m}{w\,d} I_{q\,(p+1)} \right.$$

$$+ l_1 \rho \frac{m}{w\,d} I_{b\,q_p} \frac{\alpha\,d}{m} \cdot \alpha\,a \Big)$$

$$- \left(l_1 \rho\, c_{q_p b} + l_2 \rho \frac{m}{w\,d} I_{q_p} \right) \qquad \textbf{(6r)}$$

Substitute as before

$$D_r = \frac{m}{w\,d} \rho \left\{ \left[l_1 I_{q\,(p+1)} \frac{\alpha\,d}{m} \coth \frac{\alpha\,d}{m} + l_1 I_{b\,q\,(p+1)} \frac{\alpha\,d}{m} \tanh \frac{\alpha\,d}{2\,m} + l_2 I_{q\,(p+1)} \right] - \left[l_1 I_{q_p} \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} - l_1 I_{b\,q_p} \frac{\alpha\,d}{m} \left(\alpha\,a + \tanh \frac{\alpha\,d}{2\,m} \right) + l_2 I_{q_p} \right] \right\}$$

Now $\quad I_{b\,q_p} = I_{b\,q\,(p+1)} + I_{q\,(p+1)}$

Thus:

$$D_r = \frac{m}{w\,d} \rho \left\{ \left(l_1 \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + l_2 \right) \left(I_{q\,(p+1)} - I_{q_p} \right) + l_1 I_{b\,q_p} \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \right\} \qquad \textbf{(6b)}$$

In equation **(6a)** $\quad I_{b\,q\,(p+1)} = I_{b\,q\,1} + \sum_1^p I_{q_p};$

where the first part is the current in the slot below the q conductor and the second part is the current in the q conductor below its $(p+1)$ strand. In equation **(6b)** $I_{b\,q_p} = I_{b\,q_m} + I_q - \sum_1^p I_{q_p}$ where the first part is the current in the slot below the q conductor, the second part is the current in the q conductor and the third part, as before, is the current in the q conductor from the first strand to the p strand inclusive.

With these substitutions, equations **(6a)** and **(6b)** become

$$D_d = \frac{m\,\rho}{w\,d} \left\{ \left(l_1 \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + l_2 \right) \left(I_{q\,(p+1)} - I_{q_p} \right) - l_1 \frac{\alpha\,d}{2\,m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) I_{b\,q\,1} - l_1 \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \sum_1^p I_{q_p} \right. \qquad \textbf{(7a)}$$

$$D_r = \frac{m\,\rho}{w\,d} \left\{ \left(l_1 \frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + l_2 \right) \left(I_{q\,(p+1)} - I_{q_p} \right) + l_1 \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \left(I_{b\,q_m} + I_q \right) - l_1 \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \sum_1^p I_{q_p} \right\} \qquad \textbf{(7b)}$$

Between the points at which the strands are joined together the sum of all of these differences in pressure in adjacent half-turn elements, *viz.*, $\Sigma\,(D_d + D_r)$, must be zero. In general this sum may be written in the form

$$\left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) \left(I_{q\,(p+1)} - I_{q_p} \right) - \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) I_0 - \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \sum_1^p I_{q_p} = 0 \qquad \textbf{(8)}$$

where I_0 is the sum of the $I_{b\,q\,1}$'s and the $(-I_{b\,q_m} - I_q)$'s divided by $2\,n$, that is in general

$$I_0 = \frac{1}{2\,n} \left(I_{b\,q\,1} - I_{b\,q_m} - I_q \right)$$

We will now calculate the values of I_0 for the cases that we wish to consider.

Case 1. *Strands joined at the beginning and end of each half turn.* For the q conductor of the upper coil side

$$I_0 = (q-1)\,I + n\,I \,\underline{/\theta}$$

The first part of I_0 is the current in the upper coil side below the q conductor and the second part is the current in the lower coil side which in general differs in phase by an angle θ. There are n conductors in each coil side. The current in each conductor is I amperes $(I_q = I)$.

Case 2. *Strands joined at the beginning and end of a whole turn but not turned over in the end connection.* For the q conductor of the coil:

$$I_0 = 1/2\,\{ (q-1)\,I + n\,I \,\underline{/\theta} + (q-1)\,I \}$$
$$= (q-1)\,I + n/2\,I \,\underline{/\theta}$$

Case 3. *Strands joined at the beginning and end of a whole turn and turned over in the end connection.* For the q conductor:

$$I_0 = 1/2\,\{ (q-1)\,I + n\,I \,\underline{/\theta} - (q-1)\,I - I \}$$

$$I_0 = -I/2 + \frac{n\,I \,\underline{/\theta}}{2}$$

Case 4. *Strands joined at the beginning and end of a whole coil of n turns. End connection not turned over on either side.*

$$I_0 = \frac{1}{2\,n} \sum_1^n \left[(q-1)\,I + n\,I \,\underline{/\theta} + (q-1)\,I) \right]$$

$$= \frac{n-1}{2}\,I + n/2\,I \,/\,\theta$$

Case 5. *Strands joined at the beginning and end of a whole coil of n turns. End connections turned over on one side only.* The order of the strands in the first, or lowest, conductor of the upper coil side is direct,

that of the next half turn is reverse. The strands in the second conductor of the upper coil side are in the reverse order while those in the next half turn are in the direct order.

In general

$$I_0 = \frac{1}{2n}\Big\{ (n\underline{/\theta} - 1) + (-n\underline{/\theta} - 1 - 1 + 1) + (n\underline{/\theta} + 2 - 2 - 1) + (-n\underline{/\theta} - 3 - 1 + 3) + \text{etc.} \Big\} I$$

$$I_0 = \frac{1}{2n}\Big\{ (n\underline{/\theta} - 1) + (-n\underline{/\theta} - 1) + (n\underline{/\theta} - 1) + (-n\underline{/\theta} - 1) \text{ etc.} \Big\} I$$

(a) n an even number

$I_0 = -I/2$

(b) n an odd number

$I_0 = -I/2 + I/2\underline{/\theta}$

Case 6. Strands joined at the beginning and end of a whole coil of n turns. End connections turned over on both sides. In the upper coil side the strands are all in the direct order while in the lower coil side they are all in the reverse order.

$$I_0 = \frac{1}{2n}\sum_1^n (n\underline{/\theta} + (q-1) - (q-1) - 1)\, I$$

$$= -I/2 + \frac{n\, I\underline{/\theta}}{2}$$

Consider a solid conductor of the same width, w, and same net depth, d, but which has an angle β instead of α. The current density in this conductor is

$$c = A' \cosh \beta x + B' \sinh \beta x$$

Imagine that this solid conductor is divided into m equal parts, *i. e.*, strands, in the same manner that the actual conductor is divided. The difference between the currents in the $(p+1)$ and p strands is

$$I'_{p+1} - I_p' = \frac{w\,d}{m} \frac{\sinh \frac{\beta\,d}{2\,m}}{\frac{\beta\,d}{2\,m}} \left(c'_{(p+1)c} - c_{pc}' \right)$$

(See equation 2)

But
$$c'_{(p+1)c} - c'_{pc} = \left(A' \cosh \frac{p+1/2}{m}\,\beta\,d + B' \sinh \frac{p+1/2}{m}\,\beta\,d \right) - \left(A' \cosh \frac{p-1/2}{m}\,\beta\,d + B' \sinh \frac{p-1/2}{m}\,\beta\,d \right)$$

Expand in terms of $p/m\ \beta\,d$ and $\frac{\beta\,d}{2\,m}$ giving

$$c'_{(p+1)c} - c'_{pc} = (A' \sinh p/m\ \beta\,d + B' \cosh p/m\ \beta\,d)\, 2 \sinh \frac{\beta\,d}{2\,m}$$

Thus:

$$I'_{p+1} - I'_p = \frac{w\,d}{m} \frac{2 \sinh^2 \frac{\beta\,d}{2\,m}}{\frac{\beta\,d}{2\,m}} (A' \sinh p/m\ \beta\,d + B' \cosh p/m\ \beta\,d)$$

The current in this conductor up to and including the p part is

$$\sum_1^p I'_p = \int_0^{\frac{p}{m}d} w\,c'\,d\,x = w/\beta\,(A' \sinh p/m\ \beta\,d + B' \cosh p/m\ \beta\,d) - w/\beta\, B'$$

We will now show that these values of current can be made to satisfy the relation that has been established between the currents in adjacent strands of the actual conductor. Substitute these values of $(I'_{p+1} - I'_p)$ and $\sum_1^p I_p'$ in equation (8). That is assume that the currents in the imaginary strands of the solid conductor are exactly equal to the currents in the corresponding strands of the actual conductor

$$\left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) \frac{w\,d}{m} \frac{2 \sinh^2 \frac{\beta\,d}{2\,m}}{\frac{\beta\,d}{2\,m}} (A' \sinh p/m\ \beta\,d + B' \cosh p/m\ \beta\,d) - \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) I_0 - \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) w/\beta \left(A' \sinh p/m\,\beta\,d + B' \cosh p/m\,\beta\,d - B' \right) = 0 \quad \textbf{(8a)}$$

This equation (**8a**) is satisfied if:

$$\left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) \frac{w\,d}{m} \frac{2 \sinh^2 \frac{\beta\,d}{2\,m}}{\frac{\beta\,d}{2\,m}} - \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) w/\beta = 0 \quad \textbf{(9a)}$$

and:

$$-\frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) I_0 + \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) w/\beta\, B' = 0 \quad \textbf{(9b)}$$

These conditions readily reduce to

$$\sinh^2 \frac{\beta d}{2m} = \frac{\dfrac{\alpha d}{2m}\left(\dfrac{\alpha a}{2} + \tanh \dfrac{\alpha d}{2m}\right)}{\dfrac{\dfrac{\alpha d}{m}}{\sinh \dfrac{\alpha d}{m}} + \dfrac{l_2}{l_1}} \quad \textbf{(10a)}$$

and $$B' = \beta / w \, I_0 \quad \textbf{(10b)}$$

If the total current in the conductor, actual or equivalent, is I, the vector constant A' is determined as in the preceding paper.

$$A' = \beta / w \left(\frac{I}{\sinh \beta d} - I_0 \tanh \frac{\beta d}{2} \right) \quad \textbf{(10c)}$$

By equation (**3**) the current in the p strand is

$$I_p = \frac{w d}{m} \frac{\sinh \dfrac{\beta d}{2m}}{\dfrac{\beta d}{2m}} c_{pc}$$

$$= \frac{w d}{m} \frac{\sinh \dfrac{\beta d}{2m}}{\dfrac{\beta d}{2m}}$$

$$\left(A' \cosh \frac{p - 1/2}{m} \beta d + B' \sinh \frac{p - 1/2}{m} \beta d \right)$$

$$= 2 \sinh \frac{\beta d}{2m} \left(I \frac{\cosh \dfrac{p - 1/2}{m} \beta d}{\sinh \beta d} - I_0 \tanh \frac{\beta d}{2} \cosh \frac{p - 1/2}{m} \beta d + I_0 \sinh \frac{p - 1/2}{m} \beta d \right) \quad \textbf{(11)}$$

The current in the conductor below the p strand is

$$\sum_{1}^{p-1} I_p = \int_0^{\frac{p-1}{m} d} w \, c' \, d x$$

$$= w / \beta \left(A' \sinh \frac{p - 1}{m} \beta d + B' \cosh \frac{p - 1}{m} \beta d - B_1 \right)$$

$$= I \frac{\sinh \dfrac{p - 1}{m} \beta d}{\sinh \beta d} - I_0 \tanh \frac{\beta d}{2} \sinh \frac{p - 1}{m} \beta d + I_0 \cosh \frac{p - 1}{m} \beta d - I_0 \quad \textbf{(12)}$$

The total current below the $q\,p$ strand of the actual conductor is

$$I_{bq} + \sum_{1}^{p-1} I_{qp},$$

where I_{bq} is the current in the slot below the q conductor.

If the current in any conductor and all of that below it in the slot are given the copper loss in the conductor may be calculated as described in the preceding paper. We are thus able to calculate the copper loss in any strand of any conductor. This method of calculation is far too laborious and we shall content ourselves with calculating the loss for a half turn (Case 1), a single turn (Cases 2 and 3) or for a single coil (Cases 4, 5 and 6). To do this it is necessary to obtain expressions for the voltage drop per half turn in the top element[3] of the top strand, in the bottom element[3] of the bottom strand and the voltage drop due to flux within a single conductor in all conductors below it.

The voltage drop per half turn in the topmost element of the $q\,p$ strand due to resistance and leakage below the $q\,(p + 1)$ element is,

$$l_1 \rho \, c_{qpt} + l_2 \rho \frac{m}{w d} I_{qp} + l_1 \rho \frac{m}{w d} I_{bq\,(p+1)} \frac{\alpha d}{m} \alpha a$$

The third term in this expression is the voltage drop due to flux within the insulation—of thickness a—that is immediately above the $q\,p$ strand. It is necessary to include this term in order that the voltage expressions about to be derived will be similar in certain respects to the general equation (**8**) for the currents in the strands.

By equation (**4a**) this reduces to

$$\rho \frac{m}{w d} \left\{ \left(l_1 \frac{\dfrac{\alpha d}{m}}{\sinh \dfrac{\alpha d}{m}} + l_2 \right) I_{qp} + l_1 I_{bq\,(p+1)} \frac{\alpha d}{m} \left(\alpha a + \tanh \frac{\alpha d}{2m} \right) \right\}$$

The voltage drop per half turn in the topmost element of the top strand of the q conductor of the upper coil side due to resistance and leakage flux below this element is,

$$\text{drop} = \rho \frac{m}{w d} l_1 \left[\left(\frac{\dfrac{\alpha d}{m}}{\sinh \dfrac{\alpha d}{m}} + \frac{l_2}{l_1} \right) I_{qm} + (I_{bq1} + I) \frac{\alpha d}{m} \left(\alpha a + \tanh \frac{\alpha d}{2m} \right) \right] \quad \textbf{(13)}$$

This pressure is used when the strands are numbered in the direct order. The loss in pressure per half turn in the lowest element of the bottom strand of the $q\,p$ conductor due to resistance and leakage flux below this element is:

$$l_1 \rho \, c_{qpb} + l_2 \rho \frac{m}{w d} I_{qp}$$

3. Due to resistance and flux below it.

By equation (2) this reduces to:

$$\text{drop} = \rho \frac{m}{w\,d}\, l_1 \left\{ \left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) I_{qp} - I_{b\,qp} \frac{\alpha\,d}{m} \tanh \frac{\alpha\,d}{2\,m} \right\}$$

The loss in pressure per half turn in the lowest element of the bottom—*i. e.* the q_1—strand of the q conductor of the upper coil side due to resistance and leakage flux below this element is,

$$\text{drop} = \rho \frac{m}{w\,d}\, l_1 \left\{ \left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) I_{q1} - I_{b\,q1} \frac{\alpha\,d}{m} \left(\alpha\,a + \tanh \frac{\alpha\,d}{2\,m} \right) + I_{b\,q1} \frac{\alpha\,d}{m} \cdot \alpha\,a \right\} \tag{14}$$

This pressure is used when the strands are numbered in the reverse order. The equation is written in this form so that it will be similar to equation (13). When the strands are continuous from one half turn to the next and the end connection is turned over between successive half turns the top strand of one half turn becomes the bottom strand of the next half turn. Thus in equations (13) and (14) the I_{qm} is the same as I_{q1}.

The flux in the q conductor is,

$$\phi_q = \sum_1^m (\phi_{qp} + \phi_a)$$

By equations (5) and (5a) this is,

$$\phi_q = \frac{1}{j\,\omega}\, l_1\, \rho \frac{m}{w\,d} \frac{\alpha\,d}{m} \left\{ \tanh \frac{\alpha\,d}{2\,m} \sum_1^m (I_{qp} + 2\, I_{b\,qp}) + \alpha\,a \sum_1^m (I_{qp} + I_{b\,qp}) \right\}$$

$$= \frac{1}{j\,\omega}\, \rho \frac{m}{w\,d}\, l_1 \left\{ I \frac{\alpha\,d}{m} \left(\alpha\,a + \tanh \frac{\alpha\,d}{2\,m} \right) + \sum_1^m I_{b\,qp} \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \right\}$$

The summation in the second term in this expression for the flux may be written,

$$\begin{aligned} \sum_1^m I_{b\,qp} = \Big(& I_{b\,q1} + 0 \\ & + I_{b\,q1} + I_{q1} \\ & + I_{b\,q1} + I_{q1} + I_{q2} \\ & + I_{b\,q1} + I_{q1} + I_{q2} + I_{q3} \\ & \cdots\cdots\cdots \\ & + I_{b\,q1} + \sum_1^{p-1} I_{qp} \\ & \cdots\cdots\cdots \\ & + I_{b\,q1} + \sum_1^{m-1} I_{qp} \\ = & \; m\, I_{b\,q1} + \sum_1^{m-1} \sum_1^{p-1} I_{qp} \Big) \end{aligned}$$

From equation (8) we have,

$$\frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \sum_1^{p-1} I_{qp} = \left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) (I_{qp} - I_{q\,(p-1)}) - \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) I_0$$

If the $(m - 1)$ equations for the adjacent strands are added together we have,

$$\frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) \sum_1^{m-1} \sum_1^{p-1} I_{qp} = \left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) (I_{qm} - I_{q1}) - (m-1) \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{m} \right) I_0$$

Therefore the flux in the q conductor when the strands are numbered in the direct order is,

$$\phi_q = \frac{1}{j\,\omega}\, \rho \frac{m}{w\,d}\, l_1 \Bigg[I \frac{\alpha\,d}{m} \left(\alpha\,a + \tanh \frac{\alpha\,d}{2\,m} \right) + \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) m\, I_{b\,q1} + \left(\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} + \frac{l_2}{l_1} \right) (I_{qm} - I_{q1}) - (m-1) \frac{\alpha\,d}{m} \left(\alpha\,a + 2 \tanh \frac{\alpha\,d}{2\,m} \right) I_0 \Bigg] \tag{15}$$

If the strands are numbered in the reverse order, so that the first strand is at the top and the mth strand is at the bottom, the current in the conductor below the $q\,p$ strand is $I - \sum_1^p I_{qp}$, and the $\sum_1^m I_{b\,qp}$ is now:

$$\begin{aligned} \sum_1^m I_{b\,qp} = & \; I_{b\,qm} + I - I_{q1} \\ & + I_{b\,qm} + I - (I_{q1} + I_{q2}) \\ & + I_{b\,qm} + I - \sum_1^p I_{qp} \\ & + \cdots\cdots\cdots \\ & + I_{b\,qm} + I - I \\ = & \; m\,(I_{b\,qm} + I) - \sum_1^{m-1} \sum_1^p I_{qp} - I \\ = & \; m\, I_{b\,qm} + (m-1)\, I - \sum_1^{m-1} \sum_1^p I_{qp} \end{aligned}$$

Therefore the flux in the q conductor when the strands are numbered in the reverse order is

$$\phi_q = \frac{1}{j\,\omega}\,\rho\,\frac{m}{w\,d}\,l_1\Bigg[\,I\,\frac{\alpha\,d}{m}\left(\alpha\,a + \tanh\frac{\alpha\,d}{2\,m}\right)$$

$$+\,\frac{\alpha\,d}{m}\left(\alpha\,a + 2\tanh\frac{\alpha\,d}{2\,m}\right)(m\,I_{b\,q\,m} + (m-1)\,I)$$

$$-\left(\frac{\frac{\alpha\,d}{m}}{\sinh\frac{\alpha\,d}{m}} + \frac{l_2}{l_1}\right)(I_{q\,m} - I_{q\,1})$$

$$+\,(m-1)\,\frac{\alpha\,d}{m}\left(\alpha\,a + 2\tanh\frac{\alpha\,d}{2\,m}\right)I_0\,\Bigg] \quad (16)$$

The loss in pressure as derived in equations (**13**) and (**14**) and the flux within a conductor depend upon the current in the top strand and the difference between the currents in the top and bottom strands. The current in the p strand is determined by equation (**11**).

The current in the top strand numbered in direct order, is $I_{q\,m}$.

$$I_{q\,m} = 2\sinh\frac{\beta\,d}{2\,m}\Bigg(I\,\frac{\cosh\frac{m-1/2}{m}\,\beta\,d}{\sinh\,\beta\,d}$$

$$-\,I_0\tanh\frac{\beta\,d}{2}\cosh\frac{m-1/2}{m}\,\beta\,d$$

$$+\,I_0\sinh\frac{m-1/2}{m}\,\beta\,d\Bigg)$$

Expand in terms of $\beta\,d$ and $\frac{\beta\,d}{2\,m}$

$$I_{q\,m} = 2\sinh^2\frac{\beta\,d}{2\,m}\Bigg[\,I\left(\coth\,\beta\,d\coth\frac{\beta\,d}{2\,m} - 1\right).$$

$$+\,I_0\left(\tanh\frac{\beta\,d}{2}\coth\frac{\beta\,d}{2\,m} - 1\right)\Bigg] \quad (17)$$

Likewise:

$$I_{q\,1} = 2\sinh^2\frac{\beta\,d}{2\,m}\Bigg[\,I\,\frac{\coth\frac{\beta\,d}{2\,m}}{\sinh\,\beta\,d}$$

$$-\,I_0\left(\tanh\frac{\beta\,d}{2}\coth\frac{\beta\,d}{2\,m} - 1\right)\Bigg]$$

Thus:

$$(I_{q\,m} - I_{q\,1}) = 2\sinh^2\frac{\beta\,d}{2\,m}\Bigg[(I + 2\,I_0)$$

$$\left(\tanh\frac{\beta\,d}{2}\coth\frac{\beta\,d}{2\,m} - 1\right)\Bigg] \quad (18)$$

The pressure equations which determine the resistance and reactance drops, *viz.* equations (**13**) to (**16**) inclusive are in terms of these currents in the top and bottom strands in addition to the conductor current and the current I_0. We will rewrite these equations, making the substitutions given in equations (**17**) and (**18**), and remembering that the $I_{q\,m}$ in (**17**) is the same as $I_{q\,1}$ in (**14**). We will also make the substitution shown in equation (**10a**).

Equation (**13**) becomes:

$$\text{drop} = \frac{\rho}{w\,d}\,l_1\Bigg[\,I\,\alpha\,d\,\frac{\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)}{\tanh\frac{\beta\,d}{2\,m}}\coth\,\beta\,d$$

$$+\,I_0\,\alpha\,d\,\frac{\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)}{\tanh\frac{\beta d}{2\,m}}\tanh\frac{\beta\,d}{2}$$

$$+\,(I_b - I_0)\,\alpha\,d\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)$$

$$+\,(I + I_b)\,\alpha\,d\,.\,\frac{\alpha\,a}{2}\Bigg] \quad (13a)$$

Equation (**14**) becomes:

$$\text{drop} = \frac{\rho}{w\,d}\,l_1\Bigg[\,I\,\alpha\,d\,\frac{\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)}{\tanh\frac{\beta\,d}{2\,m}}\coth\,\beta\,d$$

$$+\,I_0\,\alpha\,d\,\frac{\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)}{\tanh\frac{\beta\,d}{2\,m}}\tanh\frac{\beta\,d}{2}$$

$$-\,(I_b + I_0 + I)\,\alpha\,d\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)$$

$$+\,I_b\,\alpha\,d\,.\,\frac{\alpha\,a}{2}\Bigg] \quad (14a)$$

Equation (**15**) becomes:

$$\phi_q = \frac{1}{j\,\omega}\,\frac{\rho}{w\,d}\,l_1\Bigg[(I + 2\,I_0)$$

$$\alpha\,d\,\frac{\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)}{\tanh\frac{\beta\,d}{2\,m}}\tanh\frac{\beta\,d}{2}$$

$$+\,(I_b - I_0)\,2\,m\,\alpha\,d\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)$$

$$+\,I\,\alpha\,d\,.\,\frac{\alpha\,a}{2}\Bigg] \quad (15a)$$

Equation (**16**) becomes:

$$\phi_q = \frac{1}{j\,\omega}\,\frac{\rho}{w\,d}\,l_1\Bigg[-\,(I + 2\,I_0)$$

$$\alpha\,d\,\frac{\left(\frac{\alpha\,a}{2} + \tanh\frac{\alpha\,d}{2\,m}\right)}{\tanh\frac{\beta\,d}{2\,m}}\tanh\frac{\beta\,d}{2}$$

$$+ (I_b + I_0 + I)\, \alpha\, d\, 2\, m \left(\frac{\alpha\, a}{2} + \tanh \frac{\alpha\, d}{2\, m} \right)$$

$$+ I\, \alpha\, d\, .\, \frac{\alpha\, a}{2} \Big] \qquad \textbf{(16a)}$$

In each of these four equations I_b is the current in the slot below the conductor in question.

The writing of these equations is much simplified if we let:

$$\frac{l_1}{l_1 + l_2}\, \alpha\, d \frac{\left(\frac{\alpha\, a}{2} + \tanh \frac{\alpha\, d}{2\, m} \right)}{\tanh \frac{\beta\, d}{2\, m}} \coth \beta\, d$$

$$= M' = M_r' + j\, M_x'$$

$$\frac{l_1}{l_1 + l_2}\, \alpha\, d \frac{\left(\frac{\alpha\, a}{2} + \tanh \frac{\alpha\, d}{2\, m} \right)}{\tanh \frac{\beta\, d}{2\, m}}\, 2 \tanh \frac{\beta\, d}{2}$$

$$= N' = N_r' + j\, N_x'$$

$$\frac{l_1}{l_1 + l_2}\, \alpha\, d\, 2\, m \left(\frac{\alpha\, a}{2} + \tanh \frac{\alpha\, d}{2\, m} \right)$$

$$= T' = T_r' + j\, T_x'$$

$$\frac{l_1}{l_1 + l_2}\, \alpha\, d\, \alpha\, a = S' = j\, \frac{8\, \pi^2\, \omega\, f}{\rho\, s}\, d\, a$$

and $\frac{\rho}{wd}\, (l_1 + l_2) = R$ (the d-c. resistance of a half turn)

These equations may now be rewritten in simplified form. The resistance drop per half turn in the top element of the top strand of a conductor (**13a**) becomes:

$$\text{drop} = R \left[I\, M' + \frac{I_0\, N'}{2} + (I_b - I_0)\, \frac{T'}{2\, m} + (I + I_b)\, S'/2 \right] \qquad \textbf{(13b)}$$

If the strands are turned over in the end connections the resistance drop per half turn in the bottom element of the foregoing strand, which is now the lowest in the conductor (**14a**) becomes:

$$\text{drop} = R \left[I\, M' + \frac{I_0\, N'}{2} - (I_b + I_0 + I)\, \frac{T'}{2\, m} + I_b\, S'/2 \right] \qquad \textbf{(14b)}$$

The average resistance drop per half turn for the six cases considered is obtained from these two equations. By definition I_0 has such a value that the term involving T' in this average resistance drop is zero in every case. In order to simplify the expression we will let I_s represent the coefficient of $S'/2$. The average resistance drop per half turn is:

$$\text{av. drop} = R \left(I\, M' + \frac{I_0\, N'}{2} + \frac{I_s\, S'}{2} \right) \qquad \textbf{(19)}$$

I_s is the average sum of the $(I + I_b)$'s in equation (**13a**) and the I_b's in equation (**14a**) taken in the proper combination.

Case 1. $I_s = I + (q - 1 + n \,/\underline{\theta})\, I$ upper coil side
$= (q + n \,/\underline{\theta})\, I$ upper coil side
$= q\, I$ lower coil side

Case 2. $I_s = 1/2\, \{ [I + (q - 1 + n \,/\underline{\theta})\, I] + [I + (q - 1)\, I] \}$
$= (q + n/2 \,/\underline{\theta})\, I$

Case 3. $I_s = 1/2\, \{ [I + (q - 1 + n \,/\underline{\theta})\, I] + [(q - 1)\, I] \}$
$= (q - 1/2 + n/2 \,/\, \theta)\, I$

Case 4. $I_s = 1/n \sum_1^n (q + n/2 \,/\underline{\theta})\, I$

$$= \left(\frac{n + 1}{2} + n/2 \,/\underline{\theta} \right) I$$

Case 5. $I_s = \frac{1}{2\, n} \Big[(1 + n \,/\underline{\theta}) + (O)$
$+ (1 + n \,/\underline{\theta}) + (1 + 1)$
$+ (1 + 2 + n \,/\underline{\theta}) + (2) + \text{etc.} \Big] I$

The first term within the parenthesis is the current in the conductor plus the current below the first conductor of the upper coil side (**13b**). The second term is the current below the first conductor of the lower coil side (**14b**). This is zero. The third term is the current below the second conductor of the upper coil side (**14b**). The fourth term is the current in the conductor plus the current below the second conductor of the lower coil side (**13b**). Notice that this expression for I_s may be written:

$$I_s = \frac{1}{2\, n} \Big[(1 + n \,/\, \theta) + (3 + n \,/\underline{\theta}) + (5 + n \,/\, \theta) + \ldots + (2\, n - 1 + n \,/\underline{\theta}) \Big) I$$

$$I_s = \frac{1}{2\, n} \sum_1^n (2\, q - 1 + n \,/\, \theta)\, I$$

$$I_s = n/2 + n/2 \,/\underline{\theta}\,)\, I$$

Case 6. $I_s = 1/n \sum_1^n (q - 1/2 + n/2 \,/\underline{\theta})\, I$
$= (n/2 + n/2 \,/\underline{\theta})\, I$

The pressure acting in all conductors below the q conductor due to flux within the latter is $j\, \omega\, \phi_q$. Written in the simplified form this (**15a**) becomes:

$$\text{drop} = R\, [\, (I/2 + I_0)\, N' + (I_b - I_0)\, T' + I/2\, S'] \qquad \textbf{(15b)}$$

If the strands are turned over in the end connections, the pressure due to flux within the next succeeding half turn (**16a**) becomes:

$$\text{drop} = R\, [- (I/2 + I_0)\, N' + (I_b + I_0 + I)\, T' + I/2\, S' \qquad \textbf{(16b)}$$

Reference to the preceding paper shows that these pressure expressions are similar to those already derived for solid and finely laminated conductors except for the added terms involving S'. M' replaces M, N' replaces N and T' replaces $\alpha^2 d^2$. The expressions become identical in the limiting case of an infinite number of strands with no insulation between them.

Calculation of Copper Loss

The method of calculation is the same as that used in the preceding paper.

Case 1. When the strands are joined at the beginning and end of a half turn the copper loss in the half turn is symbolically:

$$\text{loss} = I \,.\, R\,(I\,M' + I_b/2\,N' + I_s\,2\,S') + I_b \,.\, R\,[\,(I/2 + I_s/2)\,N' + I/2\,S']$$

In this case notice that $I_b = I_0$

The first term is the power loss due to the current in the conductor and the resistance drop in the topmost element of the topmost strand. The second term is the power due to the current in the slot below this conductor and to the pressure acting on it produced by the flux within the conductor. Expanding this expression gives:

$$\text{power} = I \,.\, R\,I\,M' + I \,.\, R\,\frac{I_b}{2}\,N' + I \,.\, R\,\frac{I_s}{2}\,S' + I_b \,.\, R\,\frac{I}{2}\,N' + I_b \,.\, R\,I_b\,N' + I_b \,.\, R\,\frac{I}{2}\,S'.$$

The first term is $R\,I^2\,M_r'$. The sum of the second and fourth terms is $R\,I\,I_b\,N_r' \cos\theta_b$. The fifth term is $R\,I_b^2\,N_r'$ and since S' is a pure imaginary the sum of the third and sixth terms is zero. The expression for the power may be written:

$$\text{loss} = R\,[I^2\,M_r' + (I \,.\, I_b \cos\theta_b + I_b^2)\,N_r']$$

The phase angle θ_b is between the current, I, in the conductor and the total current, I_b, in the slot below it. Here the letters I and I_b represent the numerical values of the currents.

If this copper loss due to alternating current is divided by the loss due to the same amount of direct current, we obtain the ratio of alternating to direct-current resistance.

(a) The ratio of alternating to direct current resistance for a single half turn is:

$$K = \{M_r' + [\,(I_b/I)^2 + I_b/I \cos\theta_b]\,N_r'\}$$

(b) The average resistance ratio for a one-coil-side-per-slot winding having n layers is:

$$K = 1/n \sum_1^n \{M_r' + [\,(q-1)^2 + (q-1)\,]\,N_r'\} = \left(M_r' + \frac{n^2-1}{3}\,N_r'\right)$$

(c) The average resistance ratio for the upper coil side of a two-coil-side-per-slot winding having n layers per coil side reduces to

$$K = \left[\,M_r' + \left(\frac{4\,n^2-1}{3} + n^2\cos\theta\right)N_r'\right]$$

θ is the phase angle between the currents in the upper and lower coil sides.

If the strands are joined at the beginning and end of a whole turn the loss ratio is a little more difficult to calculate inasmuch as the losses in the two half turns are different. There are two cases to consider, one in which the end connections are not turned over and one in which they are turned over.

Case 2. Strands joined at the beginning and end of a single turn; end connections not turned over. The heating loss in the whole turn may be expressed symbolically as:

$$\begin{aligned}\text{loss} = {} & 2\,I \,.\, R\,(I\,M' + I_0/2\,N' + I_s\,S'/2) \\ & + I_b' \,.\, R\,[\,(I/2 + I_0)\,N' + (I_b' - I_0)\,T' + I/2\,S'] \\ & + I_b'' \,.\, R\,[\,(I/2 + I_0)\,N' + (I_b'' - I_0,\,T' + I/2\,S']\end{aligned}$$

The first term is the power due to the current in the conductor and the resistance drop in the top element of the top strand of the turn. The second term is the power due to the current, I_b', below the upper half turn and the pressure produced by the flux within this half turn. Similarly the third term is the power due to the current, I_b'', below the lower half turn and the pressure produced by the flux within this half turn. For the q conductor, $I_b' = I\,(q - 1 + n\,/\underline{\theta})$ and $I_b'' = I\,(q-1)$. We have also shown that in this case (2) $I_s = I\,(q + n/2\,/\underline{\theta})$, and $I_0 = I\,(q - 1 + n/2\,/\underline{\theta})$.

As before θ is the phase angle between the currents in the upper and lower coil sides lying in the same slot. Making these substitutions and dividing by the direct-current resistance loss for a whole turn gives a resistance ratio per turn of

$$K = (M_r' + (q^2 - q + n^2/4 + (2\,q-1)\,n/2\cos\theta)\,N_r' + n^2/4\;T_r')$$

The average value of this resistance ratio for a whole coil of n turns is

$$K = \left[\,M_r' + \left(\frac{7\,n^2-4}{12} + n^2/2\cos\theta\right)N_r' + n^2/4\;T_r'\right]$$

Case 3. Strands joined at the beginning and end of a whole turn; end connections turned over. The heating loss for a whole turn is now:

$$\begin{aligned}\text{loss} = {} & 2\,I \,.\, R\,(I\,M' + I_0/2\;N' + I_s\;S'/2) \\ & + I \,.\, R\,(-\,(I/2 + I_0)\,N' + (I_b'' + I_0 + I)\,T' + I\;S'/2 \\ & + I_b'\,R\,[\,(I/2 + I_0)\,N' + (I_b' - I_0)\,T' + I\;S'/2\,]\end{aligned}$$

$$+ I_b'' \,.\, R\,[-(I/2 + I_0)\,N' + (I_b'' + I_0 + I)\,T' + I\,S'/2]$$

The first term is the power due to the current in the turn and the resistance drop in the top strand of the turn in the upper coil side and the bottom strand of the turn in the lower coil side. Due to the turning over of the end connections these two half-turn strands are a part of the same strand. The second term is the power due to the current in the turn and the pressure produced by the flux within the half turn that is in the lower coil side. The third term is the power due to the current below the half turn in the upper coil side and the pressure acting on this current that is produced by the flux within this half turn. The fourth term is similarly the power due to the current below the half turn in the lower coil side and the pressure acting on this current that is produced by the flux within this half turn. In this case:

$I_0 = (-1/2 + n/2 \underline{/\ \theta})\,I \quad I_b' = (q - 1 + n \underline{/\ \theta})\,I$

$I_s = (q - 1/2 + n/2 \underline{/\ \theta})\,I \quad I_b'' = (q-1)\,I$

Making these substitutions the resistance ratio for a whole turn reduces to:

$$K = \left\{ M_r' + \frac{n^2 - 1}{4} N_r' + [\,(2\,q - 1)^2 + n^2 + 2\,(2\,q - 1)\,n \cos \theta]\,T_r'/4 \right\}$$

The average resistance ratio for a whole coil of n turns is:

$$K = \left[M_r' + \frac{n^2 - 1}{4} N_r' + \left(\frac{7\,n^2 - 1}{12} + n^2/2 \cos \theta \right) T_r' \right]$$

The method of calculating the leakage impedance when the stranding is continuous throughout a whole coil is described in considerable detail in the preceding paper and need not be repeated here. With a finite number of strands, however, there are added terms involving S' which appear on account of the insulation between the strands. Fortunately their effect is not difficult to calculate.

The added resistance drop in a coil of n turns is (equation **19**) $2\,n\,R\,I_s/2\,S'$. Values of I_s have already been calculated for the different cases. The added pressure acting in the coil side which lies in the bottom of the slot due to flux within the coil side above it is $n\,R\,(n \underline{/-\theta})\,I/2\,S'$. The other added terms are those due to the pressure acting in the conductors of the coil produced by flux within the coil itself. There are three cases, *viz.*, 4, 5 and 6.

Case 4. When the end connections are not turned over the resistance drop taken is that in the upper element of the top strand of the conductors of both coil sides. The added drop is then:

$$\sum_1^n 2\,(q-1)\,R\,I/2\,S' \quad \text{or} \quad \frac{n\,(n-1)}{2} R\,I\,S'$$

Case 5. When the end connections are turned over on one side only the resistance drop taken is that in the top element of the top strand of the first half turn plus that in the bottom element of the bottom strand of the next half turn plus that in the bottom element of the bottom strand of the next half turn plus that in the top element of the top strand of the next half turn plus, etc. In this case it is readily shown that the added drop is:

$$\sum_1^n (2\,q - 1)\ R\ I/2\ S' \quad \text{or} \quad n^2/2\ R\,I\,S'$$

Case 6. When the end connections are turned over on both sides the resistance drop taken is that in the top elements of the top strands of one coil side and the bottom elements of the bottom strands of the other coil side. The added pressure is thus

$$\sum_1^n (q-1)\,R\,I/2\,S' + \sum_1^n q\,R\ \ I/2\ \ S') \quad \text{or} \quad n^2/2\,R\,I\,S'$$

The sum of these three component added terms is the same in each of the three cases. It is $(n^2 + n^2 \cos \theta)\,R\,I\,S'$.

The average value for a single half turn is $(n/2 + n/2 \cos \theta)\,R\,I\,S'$.

We may now write the expressions for the slot leakage impedance of a symmetrical pair of fractional pitch slots.

Refer to the preceding paper.

Case 4. End connections not turned over.

$$Z = R_c \left[M' + \left(\frac{2\,n^2 - 1}{4} + n^2/2 \cos \theta \right) N' + \frac{4\,n^2 - 1}{12} T' + (n/2 + n/2 \cos \theta)\,S' \right]$$

where R_c is the true resistance of a whole coil.

Case 5. End connections turned over on one side only. Even number of conductors per coil side.

$$Z = R_c \left[M' - N'/4 + \left(\frac{10\,n^2 - 1}{12} + n^2/2 \cos \theta \right) T' + (n/2 + n/2 \cos \theta)\,S' \right]$$

Case 5. Odd number of conductors per coil side.

$$Z = R_c \left[M' + \left(\frac{10\,n^2 - 1}{12} + n^2/2 \cos \theta \right) T' + (n/2 + n/2 \cos \theta)\,S' \right]$$

Case 6. End connections turned over on both sides.

$$Z = R_c \left[M' + \frac{n^2 - 1}{4} N' + \left(\frac{7\,n^2 - 1}{12} \right.\right.$$

$$+ n^2/2 \cos\theta \Big) T' + (n/2 + n/2 \cos\theta)\, S' \Big]$$

Since S' is pure imaginary, the terms involving it do not appear in the expressions for the alternating-current resistance. In the preceding paper $\alpha^2 d^2$ which is now replaced by T' was pure imaginary. T', however, has both real and imaginary parts, and thus adds to the value of the alternating-current resistance.

There follows a numerical calculation of the heat losses in a specified winding. The pitch of the coils is one and the dimensions of the slot and the conductors are:

Width of slot (s)	= 2.54	cm.
Width of conductor (w)	= 1.60	"
Length of armature core (l_1)	= 72.4	"
Length of end turn (l_2)	= 80.0	"
Depth of strand (d/m)	= 0.254	"
Thickness of insulation between strands (a)	= 0.0381	"
Number of strands per conductor (m)	= 7.0	
Number of conductors per coil side (n)	= 2.0	
Frequency (f)	= 60 cycles	
Average temperature of w nding	= 100 deg.cent	

ρ = 2260 c. g. s. ohms at 100 deg. cent.

$$\alpha = 2\pi \sqrt{\frac{2 w f}{\rho s}} \,\underline{/45°} = 1.15 \,\underline{/45°}$$

$$\frac{\alpha d}{m} = 0.292 \,\underline{/45°}$$

$$\frac{\alpha d}{2m} = 0.146 \,\underline{/45°}$$

$$\frac{\alpha a}{2} = 0.0219 \,\underline{/45°}$$

$$\tanh \frac{\alpha d}{2m} = 0.146 \,\underline{/44°\,36.5'}\;^4$$

$$\frac{\dfrac{\alpha d}{m}}{\sinh \dfrac{\alpha d}{m}} = 1.00 \,\underline{/-0.82}\;^4$$

$$\frac{T'}{4m^2} = \frac{\alpha d}{2m} \cdot \left(\frac{\alpha a}{2} + \tanh \frac{\alpha d}{2m}\right)$$

$$= 0.0245 \,\underline{/89°\,38.5'}$$

From equation (**10a**)

$$\sinh \frac{\beta d}{2m} = \sqrt{\frac{\dfrac{\alpha d}{2m}\left(\dfrac{\alpha a}{2} + \tanh \dfrac{\alpha d}{2m}\right)}{\dfrac{\dfrac{\alpha d}{m}}{\sinh \dfrac{\alpha d}{m}} + \dfrac{l_2}{l_1}}}$$

4. From Kennelly's "Tables of Complex Hyperbolic and Circular Functions."

$$\sinh \frac{\beta d}{2m} = \sqrt{\frac{0.0245 \,\underline{/89°\,38.5'}}{1.0 \,\underline{/-0.82°} + 1.105}}$$

$$= \sqrt{0.01164 \,\underline{/45°\,1.5'}}$$

$$= 0.07628 + j\,0.07634$$

Let $\dfrac{\beta d}{2m} = g + j k$

$$\sinh (g + j k) = \sinh g \cos k + j \cosh g \sin k$$

$$= A + j B = C \,\underline{/\tanh^{-1} B/A}$$

That is $\sinh g \cos k = A$

$\cosh g \sin k = B$

Solving these two equations for g and k gives:

$$\sinh g = \sqrt{\frac{-(1 - C^2) + \sqrt{(1 - C^2)^2 + 4 A^2}}{2}}$$

and $$\sin k = \sqrt{\frac{1 + C^2 - \sqrt{(1 + C^2)^2 - 4 B^2}}{2}}$$

Substitution in these solutions shows that:

$\sinh g = 0.0766$ $\quad g = 0.0767$

$\sin k = 0.0761$ $\quad k = 0.0762$ radians

Therefore $$\frac{\beta d}{2m} = 0.108 \,\underline{/44°\,50'}$$

$\tanh \dfrac{\beta d}{2m}$ is readily computed in this case from

$$\tanh \frac{\beta d}{2m} = \frac{\sinh \dfrac{\beta d}{2m}}{\sqrt{1 + \sinh^2 \dfrac{\beta d}{2m}}}$$

$$= \frac{0.1079 \,\underline{/45°\,1.5'}}{\sqrt{1 + 0.01164 \,\underline{/90°\,3'}}}$$

$$= 0.1079 \,\underline{/44°\,21.5'}$$

$$\alpha d \,\frac{\dfrac{\alpha a}{2} + \tanh \dfrac{\alpha d}{2m}}{\tanh \dfrac{\beta d}{2m}} = 3.18 \,\underline{/45°\,19'}$$

The values of $\coth \beta d$ and $2 \tanh \dfrac{\beta d}{2}$ can be computed from the formulas:

$\coth \beta d$

$$= \frac{\sinh 2mg \cosh 2mg - j \sin 2mk \cos 2mk}{\sinh^2 2mg \cos^2 2mk + \cosh^2 2mg \sin^2 2mk}$$

$2 \tanh \dfrac{\beta d}{2}$

$$= 2\,\frac{\sinh mg \cosh mg + j \sin mk \cos mk}{\cosh^2 mg \cos^2 mk + \sinh^2 mg \sin^2 mk}$$

From which

$$\coth \beta d = 0.8835 \,\underline{/-11°\,20'}$$

$$2 \tanh \frac{\beta d}{2} = 1.472 \,\underline{/34°\,7'}$$

The complex quantities M', N' and T' may now be calculated

$$M' = 1.335 \,/\,\underline{33° 59} = 1.11 + j\,0.746$$
$$N' = 2.22 \,/\,\underline{79° 26'} = 0.408 + j\,2.19$$
$$T' = 2.28 \,/\,\underline{89° 38.5'} = 0.014 + j\,2.28$$

If the number of strands, m, is increased without limit while the depth of the conductor and the relative amount of insulation between the strands are unchanged we have:

$$\sinh \frac{\beta d}{2\,m} \doteq \frac{\beta\,d}{2\,m} \doteq \frac{\alpha\,d}{2\,m} \sqrt{\frac{a/d+1}{l_2/l_1+1}}$$

since $\tanh \frac{\alpha\,d}{2\,m} \doteq \frac{\alpha\,d}{2\,m}$

and
$$\frac{\frac{\alpha\,d}{m}}{\sinh \frac{\alpha\,d}{m}} \doteq 1$$

$$M' \doteq \beta\,d \coth \beta\,d$$

$$N' \doteq \beta\,d\,2 \tanh \frac{\beta\,d}{2}$$

For the winding we are considering,

$$\beta\,d \doteq 0.739\,\alpha\,d \doteq 1.51 \,/\,\underline{45°}$$

For this value of $\beta\,d$; $M_r' = 1.11$ and $N_r' = 0.413$. In this case, since T' is pure imaginary, $T_r' = 0$.

A further calculation has been made for conductors of the same net cross-section, but consisting of three strands instead of seven. In this case:

$$M' = 1.295 \,/\,\underline{33° 9'} \qquad M_r' = 1.084$$
$$N' = 2.04 \,/\,\underline{80° 52'} \qquad N_r' = 0.324$$
$$T' = 2.086 \,/\,\underline{87° 52'} \qquad T_r' = 0.0776$$

The following is a table of the ratios of alternating to direct-current resistance for this winding for each of the six strand arrangements.

Strand Arrangement	Resistance Ratio		
	$m = \alpha$	$m = 7$	$m = 3$
Case 1	3.17	3.15	2.70
" 2	2.76	2.75	2.46
" 3	1.42	1.47	1.66
" 4	2.66	2.66	2.40
" 5	1.01	1.08	1.41
" 6	1.42	1.47	1.66

POWER SCHEME IN COAL DISTRICTS OF NORTHERN FRANCE

The industries of Northern France, though only partially recommencing to manufacture, have discovered that competition makes extraordinary efforts to reduce production costs imperative. They see themselves displaced even in their home markets, by competition from French industrial centers which gained importance during the war on account of their protected situation, and through the development of water-power possibilities. Although they realize that the center of production in France has been perhaps permanently displaced to their disadvantage, the industrial leaders of the district are displaying a most laudable courage by laying out large sums in an endeavor to find cheap power.

Their being no water-power possibilities in the region, efforts are being directed toward the more economical employment of coal with a view to reducing power costs and permitting manufactured articles to be placed on the market at competing prices. Various coal-mining companies in the Department have constructed electric power plants driven by steam, utilizing the unsalable low-grade coal, washings, and slack at the pit mouth. Still others are in process of construction.

These plants deliver current to the industrial centers in the north of France over lines belonging to distributing companies and over Government-owned high-tension lines, which constitute a network of distributing high-voltage lines known as the Reseau d'Etat. The distribution of current produced in the mining basins is being carried out in this region by the Reseau d'Etat and five private distributing companies.

When the scheme is fully carried out, the various power stations and the industries to which electricity is furnished will be completely interconnected with a view to permitting any and all plants to deliver current to any and all consumers, thus avoiding an interruption of service in case of accident to any one generating plant.

The mining basin of the Pas-de-Calais is connected with the industrial region of the Department of the North by the Government distributing lines, and with the various cities of the Pas-de-Calais by the lines of the commercial distributing companies mentioned above

MANUFACTURE OF ELECTRICAL APPARATUS IN CHINA

The Electrical Appliances Manufacturing Co. has been recently organized and has purchased 75 acres of land in Soochow for the erection of its plant. It has made arrangements with the German Siemens Co. in Germany whereby the Chinese company will use the Siemens patents in exchange for a certain percentage of the profits of the German Company. Siemens will furnish the Chinese company a corps of experts to install and assist in the operation of the plant. The company has chosen Soochow, as land is purchased there at less than one-tenth of the price obtaining in Shanghai and the location is only 80 miles west by water and 55 miles by rail from Shanghai. Furthermore, labor costs are lower at Soochow than at Shanghai.

Mr. S. T. Sze, a brother of the Chinese Minister to Washington, is manager of the new company. This concern will manufacture electric motors and all sorts of electrical appliances suitable to the Chinese market. The present capital is given as 1,500,000 Yuan (silver), or about $800,000 gold. They expect to increase this capital as the plant develops.—*Commerce Reports.*

Polyphase Commutator Machines

BY A. B. FIELD
Assoc. A. I. E. E.
Metropolitain Vickers Electrical Co., Manchester, Eng.

In a certain type of frequency-changer which consists of an armature similar to that of a synchronous converter, viz., a type of direct-current armature with slip rings on one side and a commutator on the other, the energy loss due to the currents flowing in these conductors is here analyzed.

The energy loss appearing as heat depends upon the degree to which the currents which flow in or out at the commutator end or the slip rings compensate one another. In the case of the synchronous converter the former are direct currents while the latter are alternating currents.

In the case of the frequency-changer, they are alternating currents of different frequency.

This paper analyzes the losses taking account of the time and space overlapping of the currents and gives the results for different numbers of phases and for different power factors.

$I^2 R$ Losses in Frequency-Changers

If we have an induction motor stator connected to a polyphase source, and a commutator rotor of the same number of poles provided with, say, three-phase stationary brushes, then as we start to rotate the rotor in the same direction as the air gap field is rotating, the frequency at the brushes remains the same as that fed into the stator, but the voltage between brush studs gradually drops as the speed rises towards synchronism. Upon passing through synchronism the voltages reverse; but the direction of phase rotation remains the same, as this depends upon the sequence with which the air gap field cuts the phase bands of conductors on the rotor, and these phase bands are stationary. The frequency at the brushes also remains constant, of course.

Below synchronism, if power is drawn from the rotor the machine will be acting as a motor; that is to say the kilowatts input to the stator will be greater than the electrical output from the rotor. The rotor action itself, however, is that of a generator, and if the current drawn from the rotor is a lagging one, a demagnetizing action will be produced.

After passing through synchronism mechanical power will have to be put into the shaft when power is withdrawn from the rotor and then power will be simultaneously delivered by the stator. The relative direction of motion of any one rotor conductor and the field will have become reversed and consequently also the direction of generator current in such conductor; but the direction of the field relatively to any one phase band of rotor conductors remain as before; hence a lagging current in the circuit supplied by the rotor, which previously produced a demagnetizing action, now produces a magnetizing one, and we have so far as the rotor alone is concerned an a-c. generator whose voltage increases upon an inductive load and drops upon a capacity load. The corresponding case without a-c. excitation of the stator, would be that of a salient pole stator with the commutator brushes rotating in a direction opposite to that of the rotor. Such a generator ought to self excite when connected to an inductance; or if excited by direct current on the stator, would have a negative regulation upon an inductive load.

Coming back to the first case and making the number of conductors the same on the Δ-connected stator and rotor, as also the coil throw, but the direction of coil progression different, we have a curious combination, when this machine is driven at twice synchronous speed. If, say, an a-c. supply be connected to the stator only, a magnetizing current will be drawn from the supply, having the usual 90 deg. lag. If instead, the rotor be connected to this supply, the same amperes of magnetizing current will be drawn, but the current will be leading by 90 deg. Consequently, if both stator and rotor be connected in parallel to the supply, the magnetizing current can circulate between the stator and the rotor without any being supplied from the outside system. To obtain this circulation of magnetizing current, the small voltage required for $I R$ and leakage reactance purposes must be obtained; the former would be immediately provided by a slight shift of the brushes, causing the phase bands on the rotor to be slightly displaced from those on the stator. In this case the voltage of the machine, being controlled by the excitation current circulating between stator and rotor, would be adjusted by slight movements of the brush ring backwards or forwards. In such a machine the field rotates in the same direction as the rotor at half the speed of the rotor and consequently a rotor conductor is cutting the field in a direction opposite to that in which the stator conductor, immediately opposed to it, cuts the field, the two speeds of cutting being the same. Hence we have in the case of such a machine acting as a generator, complete compensation of the stator ampere conductors by the rotor ampere conductors immediately opposite to them. Such a machine should prove self-regulating.

In addition to the $I R$ voltage required to circulate the magnetizing current, there will be required on account of the slight magnetic leakage of stator and rotor conductors, a small component voltage in the same phase direction as that of the voltage produced by the air gap field—in phase for the rotor, out of phase for the stator. If this were not taken care of, the

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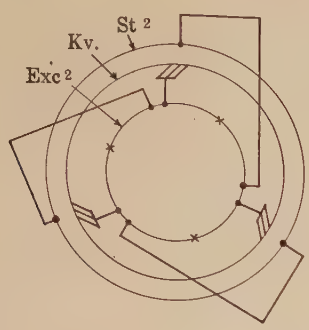
load current would divide unequally between stator and rotor. Probably a small a-c. excitation of variable voltage and field phase, will have to be inserted, the line terminals being located at centers of phases of exciter windings.



The type of machine here dealt with is that in which a commutator and set of slip-rings are connected to a common winding, the rotor thus being similar to that of a synchronous converter.

In the case of a synchronous converter, a field structure with separate excitation windings is used, but it would be possible to produce the requisite magnetizing force by alternating currents introduced at the slip-rings, or by direct current at the commutator. In fact converters have been proposed in which the whole mechanical structure remains at rest except the system of brushes which plays upon the commutator. In this case the magnetic field rotates in space synchronously with the brushes, and the external structure has neither salient poles nor windings but serves merely to close the magnetic circuit of the rotor. Although both elements, corresponding to the stator and rotor of the synchronous converter, remain at rest here, it is still necessary to employ a considerable air gap in view of the fact that the distribution of three-phase or six-phase currents in the armature winding, while nearly cancelling the distribution of direct currents over each pole pitch, do so only *on the average*, leaving relatively large uncompensated positive or negative ampere turns of armature reaction locally, which fluctuate both in time and in position relatively to the tap points and to the brushes. This feature which similarly becomes objectionable in the frequency changer discussed below, can be mitigated by chording the winding.

Now if in the above type of machine, the brushes should be rotated at a speed other than that at which the air gap field rotates, alternating current would clearly be drawn from the machine instead of direct current, and the frequency of the commutator current would correspond to the speed difference. Further, should three sets of brushes per pair of poles be evenly disposed upon the commutator instead of two, three-phase currents would be withdrawn. For mechanical convenience we may evidently bring the brushes to rest, maintaining the same relative velocities by rotating the remainder of the structure, or by rotating the wound armature only. We then have the frequency changer about to be discussed here. The proper chording of the coils to minimize the irregularities of resultant armature reaction has been specified by Lamme[1] to be approximately half the angle between consecutive brushes on the commutator; for instance, if we had six brushes on a two pole commutator the coil span would be made 150 deg. or 210 deg. instead of 180 deg.

Before considering the I^2R losses in this machine it will be well to obtain a clear picture of the conditions arising by noting a few salient features.

Fig. 1 represents diagrammatically the rotor of the machine.

Let us represent by

p the number of pairs of poles.

f_1 the frequency at the slip-rings.

f_2 the frequency at the commutator.

Then we note that

1. The magnetic field must rotate relatively to the rotor with a speed in revolutions per second of

$$n_1 = f_1/p$$

2. It must rotate in space, or relatively to the brushes on the commutator, with a speed of

$$n_2 = f_2/p$$

3. The rotor therefore has a speed of

$$(f_2 - f_1)/p$$

4. It is to be noted that (3) gives us the choice of two speeds; for f_2 may be positive, in which case the phase rotation at the commutator is the same as at the slip-rings, $A\ B\ C$, or it may be negative corresponding to a reversed direction of phase rotation on the commutator; f_1 is taken as positive always.

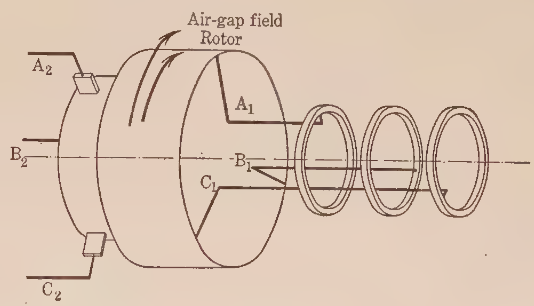


Fig. 1

5. The direction of rotation of the rotor is the same as that of the field relatively to the stator, if f_2 is greater than f_1, or if f_2 has any negative value. It is the reverse of the direction of rotation of the field relatively to the stator if f_2 is positive and less than f_1.

6. The generated voltage of the first frequency, measured from one slip-ring tap point to the next, corresponds directly to the number of armature

1. U. S. Patent No. 1318775, 1919.

conductors, the field strength, and the relative speed of field and conductors, or to f_1/p.

7. The generated voltage of the second frequency, measured between consecutive brushes on the commutator, corresponds similarly to the number of conductors, the field strength and the *same* velocity.

8. Thus if we have the armature tapped for six phase slip-rings, and brushes on the commutator for six phases also, the generated voltage of frequency f_1, between slip-rings connected to consecutive taps, will be the same as that of frequency f_2 between consecutive brushes; the currents also will be equal, barring magnetizing current and a small component which provides part of the power lost in the conversion.

9. The commutator frequency f_2 may be either higher or lower than the slip-ring frequency f_1. But if one of the two frequencies is to be a very low one, it is advisable to adopt the lower for the commutator, and this becomes essential if the lower frequency is to be subject to variation passing through zero, that is, changing its direction of phase rotation. In deciding which frequency to assign to the commutator, it will be noted that:

a. The mechanical speed is the same in either case.

b. The core loss is not greatly affected by the choice, since the field rotates at a speed corresponding to the one frequency, relatively to the stator, and the other frequency relatively to the rotor.

c. The relative speed of *rotor* and field should be high, for minimum size of machine; *i. e.*, the slip-ring frequency should be high.

d. With reference to commutation, the transformer action in the coils connected to the segments under the brush will be the smaller the lower is the frequency on the commutator side.

e. The frequency can be brought down to zero at the commutator, but not at the slip-rings.

On the whole it is usual to assign the higher frequency to the slip-rings, but no assumption on this point will be made, and the results will apply equally either way. As regards the two possible rotor speeds, we shall find that by adopting a suitable convention with regard to the sine of ϕ, the angle of displacement of current on the commutator side, the results obtained apply equally for either speed, *i. e.*, for f_2 positive or negative.

Now the currents in the rotor will result from the combination of the slip-ring currents at frequency f_1, and the commutator currents at frequency f_2.

Generally, in the case of superposed currents of two frequencies, the determination of the mean I^2R loss averaged over a few cycles, is simple, as each set of currents involves its own loss, and the net resultant loss is merely the sum of the two separate ones, irrespective of their relative magnitude or phase. In the present case, these simple relations do not hold, for although in any one conductor we have merely current of the first frequency introduced via the slip-rings, and for brief periods, we similarly have the actual current of the second frequency superposed in the same conductor, yet before one cycle is complete, the relative movement of commutator and brush has transferred this conductor into another phase group of the f_2 system.

It becomes necessary to view the cycle of events for atypical conductor, and then by a system of averages— or simple integrations— to arrive at the resultant loss.

We may start from the basis that should power be mechanically transmitted to or from the rotor, enabling the one system to operate alone, then the distribution among the arms of the delta-connected rotor of the Y-currents introduced at the slip-ring taps, or at the equivalent taps corresponding to the instantaneous positions of the brushes, will necessarily follow the ordinary $Y - \Delta$ courses; and by the symmetry of the system, the voltage upon the idle taps or brushes, as the case may be, will form a symmetrical three-phase or six-phase system. As this applies to the case of operation with power being supplied either via the commutator or via the slip-rings, the result of superposing the two will leave balanced conditions and we may therefore consider that each set of currents upon entering the rotor divides up among the delta arms in the orthodox way, so that at any instant the actual current in any conductor is the sum of the two corresponding instantaneous currents. The same reasoning may, of course, be applied to other numbers of phases than three or six on either or both sides.

We now require a simple way of viewing the life history of a typical conductor, determining for any one instantaneous value of the f_1 current the range of values of the f_2 current. We can most readily do this by reference to the only feature which is common to the two frequencies, viz.: the armature reaction. To render this process more clear, we shall on paper bring the air-gap field to rest in space by rotating the brushes on the commutator, and by readjusting the rotor speed suitably.

Assume the field to be rotating clockwise, viewed from a given side of the machine. Superpose upon the whole machine a counter clockwise rotation of f_2/p revolutions per second, thus bringing the field to rest in space while the brushes rotate counter-clockwise at this speed. Note that f_2 may be negative.

We can now readily picture the current distribution in the rotor, since the armature reaction of the f_1 currents, and again that of the f_2 currents, will be represented each by a diagram fixed in space (although slightly pulsating or varying). Although produced by currents of different frequencies, these two diagrams will have the same number of poles, and on the average will cancel one another, the one being, at every instant, nearly superposable upon the reverse of the other— if for the moment we ignore the magnetizing current.

We have two methods open to us of investigating the $I^2 R$ loss; we may do so (1) by considering the loss

occurring, from moment to moment, in the succession of conductors which occupy a point fixed in space, upon the rotor periphery; then averaging this up with respect to time, and again with respect to angular position.

Or (2) we may consider a marked conductor upon the rotor; average the loss occurring in it; and again average this up for all positions on the rotor. This latter method enables us to discriminate between conductors near to, and far from the slip-ring taps, and thus has an advantage. We shall adopt this procedure, and we shall first omit the magnetizing current, in order to make the procedure more clear.

With this omission, we have the same power factor on the two sides of the machine. That this must be so, can be seen by considerations along the following lines: The same air-gap field is responsible for causing the generated voltage of each frequency, and it is stationary in space. The armature reaction diagram of the currents of frequency f_1 must be generally similar to that of the currents of frequency f_2, except for sign since the sum of the two produces the working field and we are neglecting the magnetizing current for the present. But the armature reaction of the watt component of current of either frequency has its polar center lines at right angles to those of the air gap field. Therefore, these two component armature reactions, for the two frequencies, have their polar center lines coincident; the watt component of current of frequency f_1 must be equal to the watt component of current of frequency f_2, in order to effect balance of mechanical torque; and therefore the armature reactions of these two watt components balance one another; hence the

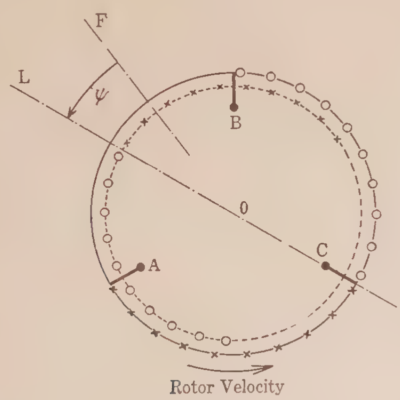


Fig. 2

armature reactions of the two remaining components must balance one another, *i. e.*, the two wattless current components must be equal and therefore the power factor must be the same on the two sides.

We shall now show, still neglecting the magnetizing currents, that for positive values of f_2 not only is the power factor the same on the two sides, but the sine of ϕ, which determine whether the current is leading or lagging, is the same; while for negative values of f_2 the power factor is the same on the two sides, but a lagging current on the slip ring side is associated with a leading one on the commutator side, and vice versa.

Fig. 2 indicates diagrammatically a two-pole rotor tapped at $A\ B\ C$ for three-phase slip rings; the line $O\ F$ represents the stationary polar center line. Assume the rotor to be driven in a counter-clockwise direction

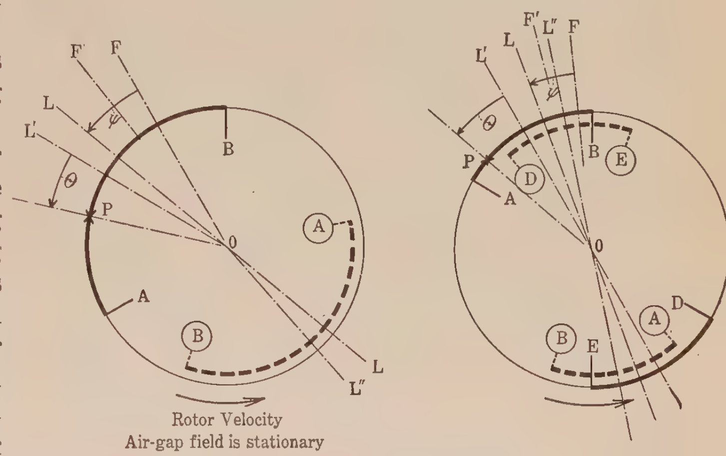


Fig. 3

mechanically and to be acting as an a-c. generator, then the current in every conductor of the $A\ B$ phase band will reach its maximum when the center line $O\ L$ of the phase band has some definite angular position, say ψ in advance of $O\ F$, where ψ may be positive or negative. If the load be noninductive ψ will be zero and the current will be a maximum in all conductors of the phase band at the moment when $O\ L$ coincides with $O\ F$. If the load be inductive and the current be lagging by an angle α, then when the current reaches its maximum in the conductors of the $A\ B$ phase band, the center line $O\ L$ will have advanced beyond $O\ F$ by the angle α, and in the well recognized manner, the conductors of the phase band will occupy such a position that the reaction of the currents in them has a component along $O\ F$ opposing the main field.

If now the points $A\ B\ C$, instead of being fixed tap points rotating with the rotor, should correspond to the momentary positions of brushes on the commutator which are rotating in a direction the reverse of that of the rotor, then the movement of the center line $O\ L$ by the angle α will be in a clockwise direction in the figure. But as the voltage induced in the conductor is due to the motion of the conductor, and not that of $O\ L$, it will remain in the same direction as before, and hence also the current in the conductor if the machine is still acting as a generator via $A\ B\ C$. In this case, therefore, a lagging current will produce a reaction having a component along $O\ F$, tending to *increase* the field strength although the machine is acting as a generator and not a motor.

Hence we have the condition already outlined for

the relative phase displacement on the two sides, *viz.*, that when f_2 is positive $\phi_1 = \phi_2$, but when f_2 is negative $\phi_1 = -\phi_2$.

We have seen that the power factor is the same on each side of the machine; it follows that the amperes per slip ring equal the amperes per brush stud, assuming the same number of phases each side, for the voltage between rings equals that between brush studs.

Fig. 3 shows a two pole rotor with chorded windings; the right hand diagram shows six phase taps brought out, and the left hand three phase taps. The region occupied by conductors of one phase, which we may call a phase band, is shown by heavy lines, dotted for the inner layer conductors and full for the outer. The tap is shown as though located opposite the slot containing the outer layer conductor to which it is connected, but the inner layer conductor to which it is also connected is indicated by a similar letter with a circle around it; this is displaced from the outer layer conductor by one coil span. $O\,L'$ represents the center line of the outer layer phase band, and $O\,L''$ the center line of the inner. The effective center line for determining the phase relations is $O\,L$ which is displaced from $O\,L'$ by half the angle of chording. It will be understood that the tap points shown may be either actual fixed taps connected to slip rings, or may represent the momentary position of brushes on the commutator; in either case the voltage generated in the phase band is the same, being produced by the movement of the conductors in the field and not by the movement of the center line of the phase band. If we are dealing with a commutator phase band the center line $O\,L$ may be rotating oppositely to the rotation of the rotor itself; *viz.*, when f_2 has a negative value.

In the figure, $O\,F$ represents the polar center line of the main field and ψ the angle, measured counter clockwise, of $O\,L$ from $O\,F$. We take the component of current in the phase band which has frequency f, to have a root-mean-square value of unity and we define its phase angle as follows:

If f is positive, $+\,\phi$ represents the angle by which the current *leads* with respect to conditions for unity power factor.

If f is negative, $+\,\phi$ represents the angle by which the current *lags* with respect to conditions for unity power factor.

In either case the power factor is $\cos\phi$ and a magnetizing armature reaction is associated with generator conditions when ϕ is positive.

It will be found that with this definition the current component of frequency f in every conductor of the phase band $A\,B$ is represented by

$$\pm\sqrt{2}\cos(\psi+\phi) \qquad (1)$$

for either direction of rotation of $O\,L$. Note that ψ is always to be measured in a counter-clockwise direction.

When we are dealing with a specific conductor P in say the outer layer, it becomes convenient to specify this by its co-ordinate measured from the center line of its phase band in the layer in question, or $O\,L'$ for the outer layer, instead of from $O\,L$, and consequently it becomes convenient to deal with the angular co-ordinate of $O\,L'$, rather than $O\,L$, with respect to the fixed field axes. It will be noted that we may still use expression (1), and define ψ therein as the angle measured counter clockwise from some suitable zero line $O\,F'$ fixed in space, to the phase band center line $O\,L'$; further the datum line $O\,F'$ will be the same whether $O\,L'$ is a center line of a slip ring phase band and therefore is fixed in the rotor, or whether it represents the momentary position of the center line of a commutator phase band and is rotating in the same direction as the rotor or the reverse. In other words, the chording angle does not enter into consideration in dealing with the difference of phase of the currents of the two frequencies in a conductor, either for positive or negative values of f_2.

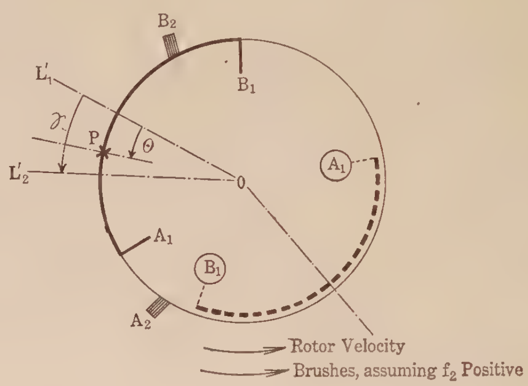


FIG. 4

Three-Phase Case

Consider now the case of three-phase slip ring taps and commutator brushes 120 deg. apart, Fig. 4, and omit magnetizing current for the present. P in the figure represents a definite conductor of the rotor; it is shown as occurring in phase band $A_1\,B_1$ of the slip ring side, and in $A_2\,B_2$ on the commutator side. It remains permanently in the $A_1\,B_1$ phase band, but passes successively through the various phase bands of the second frequency (commutator).

Currents then arise in the conductor P having values which have already been discussed and represented by (1). They have respectively the values:

$$\sqrt{2}\cos(\psi_1+\phi) \qquad \text{of frequency } f_1$$

and $$\sqrt{2}\cos(\pi+\psi_2+\phi) \qquad \text{of frequency } f_2$$

The difference $(\psi_2-\psi_1)$ may clearly have any value between $\pi/3+\theta$ and $-\pi/3+\theta$. Further, every value within this range is an equally probable one and will occur for the same number of seconds per hour of operation, on the average. We therefore require the average value of

$$2\,[\cos\psi-\cos(\psi+\gamma)\,]^2 \qquad (2)$$

for all values of γ within the range $(\theta\pm\pi/3)$, giving equal weight to each value. We shall next require

the average value of this result for all values of ψ over a range of 2π. This will give us the loss in a specific conductor; to obtain the entire rotor loss we shall have to again average for all possible values of θ, *i. e.*, between $\pm \pi/3$ in our present three-phase case.

For the loss in conductor P we have therefore:

$$\frac{3}{2\pi^2}\int_{\gamma_1}^{\gamma_2} d\gamma \int_0^{2\pi} [\cos\psi - \cos(\psi + \gamma)]^2\, d\psi$$

where

$$\gamma_2 = \theta + \pi/3$$
$$\gamma_1 = \theta - \pi/3$$

which is equal to

$$3/\pi \int_{\gamma_1}^{\gamma_2} d\gamma\,(1 - \cos\gamma) \qquad (4)$$

or to

$$2 - 1.653 \cos\theta \qquad (5)$$

If we had current of the one frequency only in the conductor, the corresponding loss would be unity, as we have taken the current to have an r. m. s. value of unity. Hence the loss, in terms of that due to current of one frequency only, is given by the above expression (**5**). This is clearly least for the mid conductor of the phase band, *i. e.* for $\theta = 0$ while it is a maximum for the two tap conductors for which $\theta = \pm \pi/3$. For these two positions the relative losses are, respectively:

Mid conductor 34.7 per cent
Tap conductors 117 per cent

Finally, averaging expression (**5**) for values of θ over its range $\pm \pi/3$ we have for the relative total rotor loss

$$2 - 1.367 \qquad (6)$$

or 63 per cent of that corresponding to the current of one frequency only.

Six-Phase Case

In the case in which six-phase provision is made on each side of the machine, the expressions become slightly modified to suit a range of θ of $\pm \pi/6$, and a range of the difference $(\psi_2 - \psi_1)$ amounting to $\theta \pm \pi/6$. Consequently expression (**5**) for the conductor loss becomes

$$2 - 6/\pi \cos\theta \qquad (7)$$

and expression (**6**) for the rotor loss becomes

$$2 - 18/\pi^2 \quad \text{or} \quad 0.176$$

so that the losses, in terms of those corresponding to the current of one frequency only, amount to

For mid conductor of phase band (min.) 9 per cent
For tap conductor (max.)............ 35 per cent
For whole rotor.................... 17.6 per cent

Losses Allowing for Magnetizing Current

We may have the magnetizing current introduced at the slip rings or at the commutator, or partly at each; and either side may be the motor side. As a matter of fact we may arbitrarily say at which side we consider the magnetizing current to be introduced, as this affects only our definition of load current in which we already have a variable phase angle ϕ at our disposal. The case will therefore remain general if we consider the magnetizing current to be introduced at the slip rings and define the load current as being the current at the commutator side, no matter at which side power enters the machine, nor which of the two currents is the greater. We later give expressions enabling the loss to be written down in terms of the current on each side of the machine and the known magnetizing current, and so avoid the necessity of considering how or where the magnetizing current is supplied.

Take, then, the magnetizing current to be introduced at the slip rings, and let the angle ϕ refer to the conditions on the commutator side and be subject to the definition already given on page 54. Take the root-mean-square value of current on the commutator side as unity, and define:

m = ratio of amperes magnetizing current to amperes load current, *i. e.* to amperes on the commutator side.

The expression to be averaged, corresponding to (2), is then:

$$2\,[\cos(\psi_1 + \phi) + m\cos(\psi_1 \pm \pi/2) - \cos(\psi_2 + \phi)]^2 \qquad (8)$$

where the upper sign is to be taken if the slip ring side is the motor side, and the lower if the generator side. Or, we may average:

$$2\,[\cos\psi \pm m\sin(\psi - \phi) - \cos(\psi + \gamma)]^2$$

between limits zero and 2π as regards ψ and the limits for γ already used for three-phase and six-phase respectively.

The result is easily found to be:

$[m^2 + 2a]$ + Average value over the γ range of

$$2\,[b\sin\gamma - a\cos\gamma] \qquad (9)$$

where

$$b = \pm m \,.\, \cos\phi$$
$$a = 1 \pm m \,.\, \sin\phi$$

the signs being subject to the conditions stated above in connection with (**8**).

For the three-phase case the limits for γ are $\theta \pm \pi/3$ and the relative conductor loss becomes:

$$[m^2 + 2a] + 1.655\,[b\sin\theta - a\cos\theta] \qquad (10)$$

while for six-phase, γ varies between $\theta \pm \pi/6$ and the relative conductor loss becomes:

$$[m^2 + 2a] + 1.91\,[b\sin\theta - a\cos\theta] \qquad (11)$$

Now a may be taken as positive except when the magnetizing current exceeds the load current being considered; and b may be positive or negative; the maximum value of (**10**) will therefore occur for $\theta = \pm \pi/3$ according as b is positive or negative; and the maximum value of (**11**) will occur for $\theta = \pm \pi/6$ according to the same conditions. Inserting these values we find for the worst conductor:

Three phase

$$1.172 + m^2 + 1.433\, m \,.\, \cos\phi \pm 1.172\, m \,.\, \sin\phi \qquad (12)$$

Six phase

$$0.347 + m^2 + 0.955\, m \,.\, \cos\phi \pm 0.347\, m \,.\, \sin\phi \qquad (13)$$

Finally, averaging (**10**) and (**11**) for variations of θ we have:

Three phase rotor loss

$$m^2 + 0.63\,[1 \pm m\,.\sin\phi] \qquad (\mathbf{14})$$

Six phase rotor loss

$$m^2 + 0.175\,[1 \pm m\,.\sin\phi] \qquad (\mathbf{15})$$

this frequency in the conductor. For any different brush stud current, I_2, we shall have a correspondingly altered slip ring current; also m will be changed, since the actual amperes of magnetizing current remain independent of I_2. However, by multiplying the previous expressions by $I_2^2\,r$ or by $I_2^2\,r'$ as the case may require, we shall have the correct loss expression

Item	Phases	Power Factor on Com.[2]	Power Factor on Slp. Rs.	ϕ (degrees)	Motor side	Amperes on Com.[2]	Amperes on Slp. Rs.	Rotor speed higher or lower	Percentage Losses Worst Cond.	Percentage Losses Rotor
Excluding magnetizing current.										
1	Three	Any			Either	1	1	Either	117	63
2	Six	"			"	1	1	"	35	17.6
Including magnetizing current, taken at 30 per cent of load current:										
3	Three	1	0.956	0	Either	1	1.045	Either	126	72
4	"	0.8 lag	0.66 lag	− 36.9	Slp. Rs.	1	1.21	Lower	183	83.7
5	"	0.8 lead	0.935 lead	+ 36.9	"	1	0.855	"	139	60.7
6	Six	1	0.956	0	Either	1	1.045	Either	43.5	26.6
7	"	0.8 lag	0.66 lag	− 36.9	Slp. Rs.	1	1.21	Lower	73.5	29.8
8	"	0.8 lead	0.66 lag	− 36.9	"	1	1.21	Higher	73.5	29.8
9	"	0.8 lead	0.935 lead	+ 36.9	"	1	0.855	Lower	60	23.4
10	"	0.8 lag	0.935 lead	+ 36.9	"	1	0.855	Higher	60	23.4

For the purpose of illustration, we give in the tabulation herewith some numerical values for the different cases discussed. We take a magnetizing current equal to 30 per cent of the current on the commutator side, or $m = 0.3$, and we give the losses as percentages, in terms of the losses due to the current at the commutator side only.

It will be found that the expressions given later, in a different form, see (**16**) to (**19**), allow a clearer appreciation of the manner in which the loss is influenced by the conditions of operation than those set down above.

The previous results may be put into a different form which will sometimes be more convenient of application. In the case of an actual machine we shall know what figure to use as an equivalent resistance r such that if I_2 is the (r. m. s.) current per commutator brush stud, $I_2^2\,r$ will be the total loss, W_2, in the armature winding due to the commutator currents alone flowing. Similarly the same value r in $I_1^2\,r$ will give us the loss W_1 due to the slip ring currents alone flowing in the armature winding, the current into each slip ring having a (r. m. s.) value equal to I_1. The magnetizing current, for which our symbol is $m\,I_2$ will similarly cause a loss, if flowing alone, denoted by W_0 and given by $(m\,I_2)^2\,r$. Further, in an actual case we shall know what value to take for r', *viz.*, an equivalent resistance such that the loss in "the worst conductor" due to the several currents taken separately is given respectively by the expressions $I_2^2\,r'$, $I_1^2\,r'$, $(I_2\,m)^2\,r'$. These losses we shall also denote by W_2', W_1', W_0' respectively.

Now the various expressions we have deduced for the mean value of the net current squared, in a conductor, or for the average value of this throughout the rotor, were based upon a commutator brush stud current such as to give unit (r. m. s.) value to the current of for a brush stud current of I_2 amperes, and we can rewrite them in terms of W_1, W_2, W_0 etc., since we have:

$$W_0 = (m\,I_2)^2\,r \quad W_1 = (a^2 + b^2)\,I_2^2\,r \quad W_2 = I_2^2\,r$$

and corresponding equations in W' and r'; and by means of these we can replace m, a, b, etc. Thus, from the definition of a, b, we have:

$$(1 - a)^2 + b^2 = m^2$$

and therefore:

$$2\,a\,I_2^2\,r = W_1 + W_2 - W_0$$

Expression (**14**) which, upon multiplication by $I_2^2\,r$ is equivalent to $[m^2 + 0.63\,a]\,I_2^2\,r$, becomes when re-written:

$$0.315\,(W_1 + W_2) + 0.685\,W_0 \qquad (\mathbf{16})$$

and represents the three-phase rotor loss; while the six-phase rotor loss is similarly found from (**15**) to be:

$$0.088\,(W_1 + W_2) + 0.912\,W_0 \qquad (\mathbf{17})$$

In precisely the same way the loss in any one conductor at position θ can be written down in the new terms, from expression (**10**) and (**11**), *viz.*

For three-phase;

$$W_0' + 1.655\cot\phi\sin\theta\,W_2' + [1 - 0.827\cos\theta - 0.827\cot\phi\sin\theta]\,[W_1' + W_2' - W_0'] \qquad (\mathbf{18})$$

For six-phase;

$$W_0' + 1.91\cot\phi\sin\theta\,W_2' + [1 - 0.955\cos\theta - 0.955\cot\phi\sin\theta]\,[W_1' + W_2' - W_0'] \qquad (\mathbf{19})$$

In expressions (**18**) and (**19**), ϕ is introduced as well as the W's. The conditions of operation are really completely defined when we are given the values of the three W's, a statement as to which side is the motor side, and the two frequencies (including their relative signs); hence the presence of ϕ might be avoided. In fact an inspection of the vector diagram for the three current components (f_1 load, f_2 and f_1 magnetizing) will reveal that

$$\sin \phi = \pm \frac{W_2 + W_0 - W_1}{2\sqrt{W_2 W_0}}$$

the upper or lower sign being taken according as the slip ring side is acting as the motor or generator side. Hence ϕ might be eliminated by means of this equation; or alternatively, in an actual case it may be determined from this equation, if not independently known, and the value used in the expressions given.

The reference numbers of the expressions derived in this chapter for the conductor and rotor losses under various conditions and allowing for magnetizing current are collected below for convenience of reference;

	Three-Phase	Six-Phase
For loss in whole rotor.....	14	15
Ditto, in terms of W_0, W_1, W_2	16	17
For conductor loss.........	10 (12)	11 (13)
Ditto, in terms of W_0', etc.	18	19

Electric Power Application to Passenger and Freight Elevators*

BY HARRISON P. REED
Fellow, A. I. E. E.
Cutler-Hammer Manufacturing Co., Milwaukee, Wis.

This Committee has been requested to report on the application of electric power to passenger and freight elevators. An enormous amount of electric energy is used for the operation of elevators and it is therefore fitting that the problem be studied from a power economy standpoint as well as from the more important standpoint of protection to life and limb.

It is assumed that the reader knows little of this subject and that practically nothing up-to-date has been published. It is not believed that the reader will be particularly interested in accurate technical details, but that he will want to know the range of application of elevators, their motors, controllers and all safety appliances as represented by best present practise.

Included in this report are six chapters as follows:

I. History and service requirements.
II. Types of elevator machines and the limitation of each.
III. Charateristics and limitations of d-c. and a-c. motors.
IV. Elevator controllers.
V. Brakes and other safety accessories.
VI. Power consumption.

I—HISTORY—SERVICE REQUIREMENTS

Historical

The history of the elevator dates back to 236 B. C. which date is mentioned by Vitruvius describing an elevator built by Archimedes in that year. This "elevator" was operated by man-power applied to a capstan revolving a drum on which hoisting ropes were wound.

According to Prof. Coburn, of Philadelphia, who has made extensive archaeological studies in Palestine, the palace of Nero had three elevators.

It is reported that Prof. Commadatore Boni, the celebrated Italian archaeologist, while exploring some underground passages near the north rostra of Caesar, discovered twelve small galleries which he claims are traces of a former system of elevators, as in each room there are grooves through which ropes passed and stone supports for wooden poles are fixed vertically inside the passages.

An early mention of an elevator is made in a letter of Napoleon I to his wife, the Archduchess Maria Louise.

A Brussels paper not long ago stated that the apparatus which takes an occupant from the ground floor to the top of a building in a few seconds is not a new invention, as an ingenious contrivance was constructed in the seventeenth century by Velayer of Paris who called his invention "the flying chair." It was not merely a toy but became very fashionable among the rich people on account of its utility. It consisted of a chair hung by a rope passing over a pulley and counterbalanced by a weight. It continued in operation until a serious mishap occurred to the King's daughter at Versailles.

No doubt the elevator as we know it evolved from the so-called "flying chair." Only since 1850 has real progress been made in elevator development. In that year George H. Fox made an elevator operated by the motion of a vertical screw, the nut being carried on the cage.

The steam elevator, now practically extinct, was introduced over half a century ago. This stimulated increased building heights but successful service was limited with this type of machine. About 1880 the hydraulic elevator came into use and it practically superseded the steam machine at that time. However,

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HARRISON P. REED, Chairman.
HENRY F. BEWLAY, Roth Bros. Co., Chicago, Ill.
H. D. JAMES, Westinghouse Elec. & Mfg. Co., Pittsburgh, Pa.
PAUL M. LINCOLN, Lincoln Electric Co., Cleveland, Ohio
NILS O. LINDSTROM, A. B. See Elevator Co., Jersey City, N. J.
DAVID L. LINDQUIST, Otis Elevator Co., New York, N. Y.
ERNEST B. THURSTON, Haughton Elevator & Machine Co., Toledo, Ohio

building heights were limited by brick bearing walls inasmuch as steel-framed structures were not known. The introduction of steel building frames made the limit of building heights a commercial rather than an engineering problem.

The electric elevator was invented about 1885 and the first installation was made in 1887, but it was not developed sufficiently for extensive use until approximately the year 1893. Still, many hydraulic elevators were installed, although many were equipped with electrically driven pumps. Even with this arrangement the hydraulic elevator consumes more power than the electric elevator. During the past ten years there has been a decreasing number of hydraulic elevators installed. The electric machine has practically superseded all other types. This is true because the electric elevator is more readily equipped with suitable safety features, it occupies less space in the building, its initial cost is less, it is more easily controlled, and the power consumption and repair bills are smaller.

It is estimated that in any large city more people are carried daily by passenger elevators than by all street cars and subways combined. It is extremely important therefore that elevator travel be safe. It is almost equally important that for the service required the electric power consumption be reduced to a minimum.

SERVICE REQUIREMENTS

1. *General Requirements.* The initial elevator problem is one of service. So many factors enter into this problem that each individual case must be considered as a separate problem in itself. However, some accepted general rules may be stated for the guidance of elevator selection.

The service to be rendered depends upon the number of passengers, or the weight and bulk of freight to be carried, and upon the number of floors served. It is limited by the time taken for loading and unloading as well as by the time consumed during acceleration and retardation, and by the time consumed during travel at full speed.

For many stops per car-mile the important factors are quick starting and stopping, and quick loading and unloading. For few stops per car-mile the more important factor is higher running speed. In many installations accurate stopping is also extremely important.

We can consider elevators as vertical railways, running express or local, as the service may require, and when they are so arranged that they carry the number of people that arrive at or depart from the building in a given time, and distribute them on the various floors, or bring them to the street level, the elevator service may be considered 100 per cent of that required. The same applies to material-carrying elevators relating to the service of delivering incoming and outgoing material so that it does not accumulate anywhere.

In order to give passenger elevator service in a building, it is necessary to consider the number of persons that enter and leave the building, morning, noon and night, and also the number of people that enter and leave between these times.

The building height and floor area are not the only things that are needed to determine elevator service, although they must be considered in connection with the local regulations with reference to speed.

The elevators must have a given capacity in pounds and should be capable of running at a certain maximum speed with this load.

The passenger elevator car should be constructed with reference to its opening towards the hall so that a number of persons can enter or leave at the same time, making a car rather shallow in depth, but wide. The dimensions of a freight elevator car depend much upon the material to be handled, but quick loading and unloading should be a consideration in the determination of the car size.

Elevators should be capable of accelerating and retarding as rapidly as local power conditions will permit with, however, due consideration of effect on passengers and power consumption during starting and stopping.

The number of elevators required of the express or local type should be determined from the number of people that it is necessary to carry per hour, and the grouping of these elevators should be considered with reference to the entrance to the street or streets so that the movement of traffic may be distributed to best advantage.

Elevators should be durably and economically constructed, so that if ordinary care is exercised in their maintenance, only small inexpensive, interchangeable parts need be replaced in order to keep the elevators in fit condition for continuous service. The major parts should last indefinitely without replacement.

The direct-current elevator was the first to be perfected because of the fact that we had no suitable a-c. motor for elevator service prior to 1905. Even after the development of the a-c. induction motor the d-c. motor was better suited to elevator service due to the ease with which speed control can be obtained under varying loads. However, it has been found difficult to obtain direct current in outlying sections of our cities especially, and in some cities direct current is unobtainable. It is therefore necessary to use such power as is available, and in the application of the alternating-current motor to elevator work of the higher speeds, it has been found that it cannot compete with the direct-current motor in the present state of the art due to the inherent characteristics of the single-speed induction motor. There are, however, several types of multi-speed alternating-current motors especially designed for elevator service that are performing very satisfactorily on speeds up to about 300 ft. per min. and when properly installed, the service given is comparable

with the direct-current elevator of the same speed. However when applied to higher speeds, a number of complications arises because the alternating-current motor does not lend itself to the refinement of control possible with the d-c. motor.

2. *Speeds and Capacities.* Heights of buildings are not limited by weight and speed limitations in elevator equipment. Elevators have been built for speeds up to 700 ft. per min. for passenger service, up to 30,000 lb. lifting capacity for freight service, and up to 100,000 lb. for special forms of electric hoists such as car dumpers.

The speed of the elevator for any particular service is very difficult to determine satisfactorily to everyone as it is more often personal opinion than engineering judgment that decides this detail.

As a general guide for estimating, the following will serve as representative of present practise:

Passenger Service—Office Buildings, etc.

Total Travel	Maximum Car Speed
Feet	Ft. per min.
0 to 50	50 to 300
50 to 75	300 to 350
75 to 100	350 to 400
100 to 150	400 to 500
150 up	500 to 550

Express service—550 to 600 ft. per min.

The above is for direct current and for operator-controlled cars. For automatic push-button service 300 ft. per min. is usually considered the limit of speed, as the automatic elevator is inherently a time waster inasmuch as the person within the car has complete control and runs the car without regard to the floor demands. It should be noted that 700 ft. per min. is not given in the table principally due to the fact that many state and city codes limit the speed to 600 ft. per min. For alternating current 400 ft. per min. is considered the limit although very extensive developments are being carried out at the present time by many manufacturers, the results of which they hope will make it practicable to use a-c. motors in connection with elevators traveling at a higher rate of speed.

The values in the above table are entirely dependent upon the average number of stops per mile of car travel. For example, in department store service where stopping at every floor is required for sales reasons, 350 ft. per min. is the maximum desirable speed because above this the car would not attain full speed between floors and therefore would give very inefficient operation; 250 ft. per min. is about the accepted correct average speed for this service. In office buildings of eight stories or less, the number of stops per mile generally ranges from 150 to 200. In office buildings above eight stories the number of stops will range from 125 to 175 per mile for local service, while for express service we can expect 50 to 150 stops depending upon whether service is given to several upper floors or to only a club or restaurant on one floor.

The capacities of passenger elevators vary from about 1000 lb. in residences to 5000 lb. in department stores, and from 2000 to 3000 lb. in office buildings. The capacity determines the car size which should be of sufficient floor area to provide not over 75 lb. per square foot. This is an accepted standard throughout the United States.

The number of elevators required to supply a given service is very difficult to determine accurately because each building is an individual problem in itself, due to the large variation in the demands such as internal traffic, insurance office traffic, consulting office traffic, etc. Consequently we can use only similar buildings for estimating an approximate average. The following method may be used as a guide for determining the number of elevators required in a building of known dimensions.

The population can be estimated from the rentable area as follows:

New York City—75 to 100 square feet per person.
Other large cities—100 to 130 square feet per person.
Small cities—125 to 150 square feet per person.

Total travel in feet if not known can be estimated by assuming 17½ feet for the first floor and 12½ feet between other floors.

Floor area of car platform:
27 sq. ft. for 2000 lb. for medium height buildings.
33 sq. ft. for 2500 lb. for standard office building capacity.
40 sq. ft. for 3000 lb. for special service where a lift for safes is required or the time schedule of leaving the first floor is not a feature.

The normal capacity of a car in passengers without crowding is determined by allowing two square feet per person including the operator.

The estimated time for synchronizing the cars, loss in time due to accelerating and retarding, loading and unloading at the first floor is 27½ seconds. The estimated time for accelerating and retarding, loading and unloading for each floor above the first is 7 to 8 seconds, or if positive door locks are used, 8 to 10 seconds.

The estimated time required to empty the building above the first floor usually ranges from 40 to 60 minutes.

The following is an example of an office building calculation for New York City.

Rentable area above first floor..............	190,000 sq. ft.
Travel first to sixteenth floors—All local.......	192 ft.
Car capacity. 2500 lb. 33 sq. ft............	15 persons
Speed of car..................................	550 ft. per min.
Positive door locks used	
Time required to empty building............	45 min.
Estimated stops per mile of travel..........	150 stops
Estimated sq. ft. per person in building........	80 square ft.
Population of building = 190,000 ÷ 80......	2375 persons
Number of trips to empty building = 2375 ÷ 15..................................	159 trips
Time lost. Stops at first floor = 27.5 + 2....	29.5 sec.

Actual running time per round trip $= \frac{2 \times 192 \times 60}{550}$	42 sec.
Total round trip travel $= 2 \times 192$	384 ft.
The average number of feet between stops $= 5280/150$	35 ft.
Number of stops above first floor $= 384/35 - 1$	10 stops
Stopping time above first floor $= (7\frac{1}{2} + 2) \times 10$	95 sec.
Total time of round trip $= 29.5 + 42 + 95$	166.5 sec.
Total time of round trip	$2\frac{3}{4}$ min.
Time required for one elevator to empty the building $= 159 \times 2\frac{3}{4}$	437 min.
Number of elevators required to empty building in 45 minutes $\times 437/45$	10 elevators

From the above it will be seen that during the rush hours ten elevators with a capacity of 2500 lb. at 550 ft. per min. will give approximately 17-second service leaving the first floor. For the other hours of the day eight elevators will handle the traffic and give 20-second service from the first floor. If 15-second interval service is required eleven elevators will be necessary. This question of time interval must always be checked before definitely determining the number of elevators.

These calculations can only represent average conditions as the human element enters into the problem to a considerable degree. For example, the time the car will be stopped at a floor varies from 4 to 12 seconds depending mainly on the characteristics of the people served.

On page 59 is given a table of speeds for various rises as representative of present practise. It is interesting to note the effect of a change in speed upon the passenger-carrying rate and upon the power consumption per car mile.

Since an elevator doing local service in an office building of fifteen stories or less spends nearly as much time in starting and stopping as in running at full speed, the energy consumed in accelerating and retarding becomes an important factor. The energy required to accelerate to full speed is present in the moving system in the form of kinetic energy, but with most methods of control in use very little of this energy is recovered in stopping. The energy that must be stored in the machine, car, counterweight, cables, etc. for each start depends upon their mass times the square of the velocity to which they are accelerated.

It is, therefore, evident that increased car speeds must be accompanied by a considerable increase in the power consumption per car mile. It remains to be seen what effect a change in car speed will have upon the carrying rate of the elevator.

For the sake of comparison the foregoing office building calculation will be analyzed for a car speed of 450 instead of 550 ft. per min.

All other values except the following remain the same as before:

Speed of car	450 ft. per min.
Actual running time per round trip $= \frac{2 \times 192 \times 60}{450}$	51.3 sec.
Total time of round trip $= 29.5 + 95 + 51.3$	175.8 sec.
Total time of round trip	2.93 min.
Time of one elevator to empty building $= 159 \times 2.93$	465 min.
Time required for 10 elevators to empty the building	46.5 min.
Interval of service	17.58 sec.
Estimated car miles per day (10 elevators)	120 car miles
Estimated car miles per year (10 elevators)	36,000 car miles
Estimated kw-hr. per car mile saving by using 450 ft. per min. instead of 550	0.8 kw-hr.
Kw-hr. per year saved $= 0.8 \times 36{,}000$	28,800 kw-hr.
Dollars per year saved at \$0.01 per kw-hr.	\$288.00

The amount of saving per car mile due to the reduced speed may vary as much as two-to-one in individual cases. The above figures are merely given as an illustration and not as a guarantee in any sense of the word. The price of power at \$0.01 per kw-hr. is given so that knowing the power rate in any locality the saving may be easily calculated.

The above analysis shows that the decrease in speed increases the time required for the ten elevators to empty the building from 43.7 to 46.5, or 2.8 minutes, and increases the time interval from 16.65 to 17.58 seconds, or less than one second.

The use of the lower-speed elevators increases the time required to empty the building by an amount that is probably much less than the errors that would be made in the original assumption.

This analysis is not submitted as a more nearly correct solution of the problem but is simply to illustrate the effect of changing the car speed. It is probable that if building owners fully realized how much they are paying for higher elevator speeds and how little they are really gaining by them, there would be a downward revision of elevator speeds for buildings of this class.

Freight Elevators. Freight service is extremely varied, ranging from 1000 to 30,000 lb. short and long travel, and at speeds of from 30 to 250 ft. per min. The determining of the correct freight speed is not so difficult because the service is usually fairly well known. The cost of installation increases very rapidly with increase of speed with the result that speed is often sacrificed for first cost which explains why very few freight elevators above 100 ft. per min. are in use except in plants where an enforced system of manufacture is maintained. This means really two different demands. First, for isolated installations, storage, small plants, etc., speed ranging from 30 to 100 ft. per min. and for large manufacturing plants requiring speed from 100 to 250 ft. per min.

It has been proved very conclusively that a speed above 250 ft. is not warranted except for special

service because only a small fraction of the total time is running time.

The required capacity of freight elevators is usually known because the material to be handled is known. The tendency of large manufacturing plants is to use some type of power driven truck which is usually very heavy, so this demands elevator capacities from 5000 to 15,000 lb.

Service or capacity of elevators is affected by safety appliances such as door and gate interlocks inasmuch as the introduction of these devices increases the time for loading and unloading. Thus the extension of safety appliances tends to increase the number of elevators installed. This is unfortunate, but the safety consideration is so vastly important that the reduction of service efficiency is not to be deplored.

II—THE ELEVATOR MACHINE

General

The electric elevator is made up of three principal parts:

1. The car, consisting of the car frame and enclosure with such control and safety apparatus as is necessarily attached to the car.
2. The shaft work, consisting of the guides, counterweights, buffers, limit switches, etc.
3. The hoisting engine, with motor, brake, controller and cables.

The car should be made as light as practicable so as to keep down the load on the machine bearings and also so as to assist in keeping down the power consumption.

The elevator guide rails are of great importance in connection with efficient and safe operation of the elevator, as the smoothness of operation in the car is largely dependent upon good elevator guides, properly installed. The guides must be uniform in size, straight and installed in exact alignment. It is best to have the guides machined and the ends tongued and grooved for accurate connections with fish plates.

The electric elevator hoisting engine is a simple mechanism consisting of a grooved drum or driving sheave over which the hoisting cables pass from the car to the counterweight, and a mechanical brake. In most cases a gear-reduction mechanism running in oil is incorporated between the electric motor and the driving sheave.

Location

Infrequently the elevator machine is installed in the basement of a building. Probably 98 per cent of all new installations in the United States use an overhead machine installed in a room called the "pent-house" at the top of the building. Basement installations are objectionable because they require much longer hoisting cables and more idler sheaves than for overhead machines; they occupy valuable space in the basement and in many cases the actual load on the building is greater. Placing the machine directly over the hoistway imposes a load on the building equal to the weight of the hoisting machine, plus the loads on the car and counterweight ropes, whereas placing the machine below, imposes a load on the building equivalent to twice the loads on the car hoisting and counterweight ropes. Therefore, if the hoisting engine weighs less than the combined loads on the car and counterweight ropes, placing the machine overhead reduces the load on the building. This relation of weights often occurs.

Roping

The different types of machines according to roping are: Winding drum, full-wrap traction, and half-wrap traction (generally known in this country as the "V" groove traction and abroad as the "wedge drive" traction.)

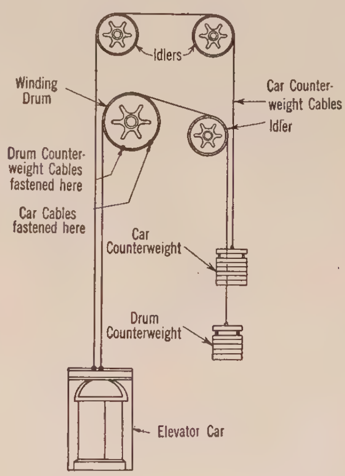


Fig. 1—Typical Roping for Overhead Drum-Type Elevator

The winding-drum machine predominated in earlier elevator history, but for passenger service it is gradually being superseded by either the full-wrap traction or the half-wrap traction elevator. Even for freight service many traction-type elevators are now being used. The following will give a clearer idea of the three types of elevators.

Winding-Drum Machine. The method of roping is shown in Fig. 1. Three sets of cables are used. The first set or hoisting cables is attached at one end to the winding drum and at the other end to the car. The drum counterweight cables are also attached at one end to the winding drum but the other ends of these cables are fastened to the drum counterweight. The third set lead from the car, over idlers, to the car counterweight. The drum is machined with spiral grooves so that as the hoisting cables wind up, the drum counterweight cables unwind.

This type of elevator is limited to relatively short travels (not over about ten stories) due to the fact

that the drum length becomes unwieldy on longer travels.

If the drum-type machine is installed overhead it will give remarkably long cable life because there is no possible cable creepage and the bending is always in one direction. However, if the machine is installed in the basement, reverse bends are necessary in the cables and this materially reduces the cable life. A car counterweight is used with the larger cars to reduce the load on the drum and drum bearings. One reason for the decreased use of the drum machine is because it requires a modification of the machine for each installation, as the length of travel determines the length of the winding drum. Another bad feature is that should the terminal stops and overtravel limit switches fail to stop the car at the terminals, the machine may continue to travel and finally pull the cables from their sockets.

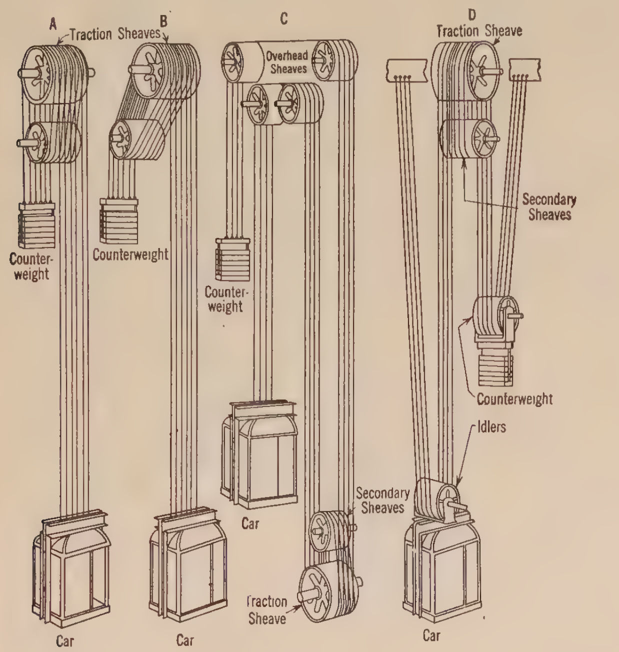


Fig. 2—Roping for Full-Wrap Traction Elevators

Full-Wrap Traction Machine. The roping for various full-wrap traction machines is shown in Fig. 2. This machine, cabled directly one-to-one, or two-to-one, has the advantage of being a standard stock machine for all lengths of travel. The driving sheave has parallel round grooves, the driving of the car being dependent upon the friction between the cables and these grooves. To get sufficient traction an idler is necessary so as to get the equivalent of a full wrap around the traction sheave. A great advantage of the traction machine, both half-wrap and full-wrap is that if the limit switches fail to stop the machine at the terminals, the landing of either the car or the counterweights will slacken the cables and allow the machine to overrun without moving the car.

One possible objection to this type of machine is that the driving sheave bearing is required to take double load due to the double wrap necessary in this form of drive. This produces a somewhat lower efficiency than could otherwise be realized. Because of the round grooves the traction is limited but it does not change much with wear as it does in the case of the half-wrap traction machine.

Half-Wrap Traction Machine. For the method of roping used, see Fig. 3. It will be noted how simple the roping is, there being only two cable bends (one as the cable leads onto the driving sheave and the other as it leaves), where the driving sheave diameter is one-half the car width, although this is doubled when a deflecting sheave is necessary. However, for loads above approximately 15,000 lb. a two-to-one roping is generally used. As the car width increases to a point where it is impracticable to further increase the diameter of the driving sheave, the amount of "wrap" possible on the driving sheave decreases. Therefore in the case of wide freight cars it is sometimes necessary to use the full-wrap traction machine in order to get sufficient driving friction. The driving sheave bearing load is only one-half that of the full-wrap traction machine.

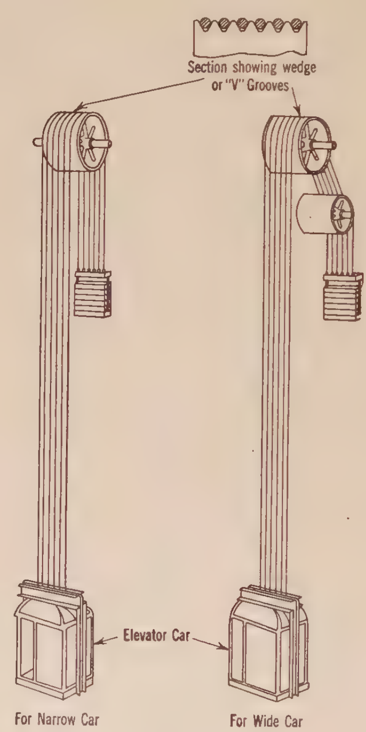


Fig. 3—Roping for Overhead Half-Wrap Traction-Type Elevator

One criticism of this type of elevator is the wearing of grooves in the sides of the V, thereby reducing the pinching action, although sheaves properly machined are still in good operating condition after eight or ten years of constant regular service. Moreover the rim in which the grooves are cut can readily be made removable for replacement.

The traction elevator has the advantage of being a standard or stock machine for all lengths of travel. If the limit switches fail to stop the car, the landing

of either the car or the counterweights will slacken the cables and allow the machine to over-run without straining the hoisting cables.

It is still an open question whether the full-wrap or the half-wrap traction machine is the better. Cable life is generally a little longer on the half-wrap machine, but the wear of the V grooves is still a problem.

Gearing

Elevator machines have been built gearless or with the following types of gearing: Single worm and gear, single herringbone gear, tandem worm and gear, single worm and gear with external spur back-gearing, single worm and gear with internal spur back-gearing and car leveling single worm and gear.

Gearless Elevator. The gearless elevator is shown in Fig. 4. It requires a very low-speed direct-current motor, because the driving sheave diameter is usually made not less than forty cable diameters in order to obtain reasonable cable life, and therefore to obtain the desired elevator speed a motor having a speed of 65 rev. per min. or less is used. Due to this limitation, car speeds with the gearless machine lie between 400 and 700 ft. per min. It is a very smooth and quiet operating machine and gives a high full-speed operating efficiency for long travels. As yet this machine is generally built in the full-wrap traction type which reduces the full-speed running efficiency somewhat.

The low-speed motor design inherently means a very large machine and therefore to keep the size down only a small range of speed is obtained by a change in shunt field. It is therefore necessary to use either series-parallel resistors in the armature circuit or multiple voltages applied to the armature in order to obtain adequate speed control. The series-parallel resistor method is a low-efficiency method of starting and stopping. Where alternating current only is available a synchronous converter may be used. Sometimes multi-voltage control is considered, which requires a motor-generator set to supply the multi-voltage. The stand-by losses of this set reduce the operating efficiency. If direct current is available, a storage battery may be used to supply the multi-voltage.

The gearless machine roped two to one, allows a motor of twice the speed of that of the one to one for the same elevator car speed and therefore a higher speed can be used and the motor built on a smaller frame. This type of machine is usually used for car speeds of 400 to 500 rev. per min. It is a smooth and quiet operating machine. Its speed is also controlled generally by series-parallel resistors. This machine has until recently been built in the round groove, full-wrap traction type, giving ten cable bends and a lower full-speed running efficiency. There has lately been installed a half-wrap machine, reducing the cable bends to six. The number of cable bends is then equal to the one to one, so the efficiency is doubtless about the same as the one to one.

Single Worm and Gear Machine. This machine (see Fig. 5) covers a wide field of application as it is used with drum, full-wrap traction, half-wrap traction and two to one cabling, for car speeds from 50 to 500 ft. per min. In car speeds up to 300 or 400 ft. per min. it has been a standard almost ever since electric elevators were built. Due to special effort in the motor and controller design and special attention to design and workmanship of the machine and gears, some machines of this type are now working at car speeds of 600 ft. per min. with smooth and quiet operation.

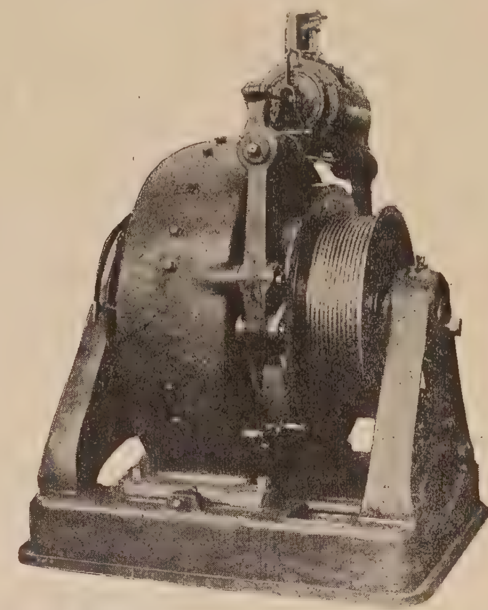


Fig. 4—Gearless Traction Elevator Machine

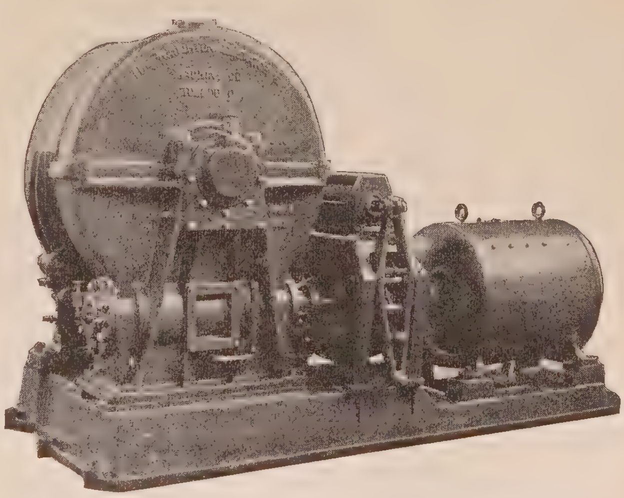


Fig. 5—Single-Gear Traction Elevator Machine

While the full-speed running efficiency is less than that of the gearless machine, its actual operating efficiency with the shunt field controlled motor is usually higher on any service requiring many stops per car mile. The better operating efficiency becomes more and more of a factor as the number of stops per car

mile increases. Another feature of value is that the winding sheave diameter is not limited and can in most cases span one-half of the car depth, thereby eliminating all idler sheaves and increasing the cable life.

A possible objection to this type of elevator for high car speeds is that it requires long experience and the highest class of manufacture to produce a smooth and quiet operating machine. Another objection, gear wear, has not proved to be a factor, as after six years of regular operation it is insignificant and promises to give twelve to fifteen years of continuous operation before any gear replacement is necessary.

Single-Gear Herringbone Machine. This machine has been tried extensively, giving very efficient operation, but it is understood that it is expensive to cut gears that insure quiet and smooth operation. This fact has limited its use.

Tandem Worm and Gear Elevator. The tandem-gear machine (Fig. 6) has been in use practically from the date of the earliest electric elevators and has stood its own, although at present there is a tendency

FIG. 6—TANDEM-GEAR TRACTION ELEVATOR MACHINE

to manufacture the single-gear machine roped two-to-one, which of course is relatively hard on cables. The field of the tandem-gear elevator is heavy duty continuous service since it minimizes gear pressure by using three points of gear contact. The majority of elevators used in rubber and automobile plants which demand the most severe service, is tandem geared.

There seems to be an impression that a thrust gear is a poor thrust bearing, and so it would be were it not for the fact that this thrust gear delivers its thrust to lift one-half of the load.

Single Gear with External or Internal Back Gearing. This machine is like the standard single worm and gear machine shown in Fig. 5 except that between the gear and drum shafts is a spur gear reduction not ordinarily oil immersed. The reason for this is to enable a small machine to lift a heavy load where the service is intermittent and first cost is a determining factor. It is a question of judgment whether to use this type or the single-gear elevator roped two to one.

Car-Leveling Single Worm and Gear Elevator. The car-leveling elevator has a certain field where it is very essential that the landing stops be accurately within one-quarter inch, plus or minus, with the landing. This is accomplished with shunt field control of d-c. motors whereby a low enough speed with high enough torque can be obtained; or by applying a low-frequency to a regular a-c. elevator motor, or by the use of an additional small geared machine arranged to drive the regular hoisting motor and brake shoes at a low speed.

COUNTERWEIGHTING AND CABLE COMPENSATION

To get best operating efficiencies it is essential that both of these subjects receive careful consideration. Many elevators are running today with insufficient counterweight, and with no cable compensation on jobs where the rise is great and therefore compensation should be used.

Counterweighting. It is obvious that an elevator without any counterbalance will be very inefficient because the motor horse-power required would be relatively large. It is customary therefore first to supply sufficient counterweights to balance equally the elevator car. Then enough additional weight is added to equal the estimated average load. This additional counterweight is generally known as "over-counterweight." The amount of over-counterweight is usually between 30 and 40 per cent of the maximum rated capacity of the elevator. In rare cases this amount is made 50 per cent, where full load is carried by the elevator nearly every trip. In any case the over-counterweight never exceeds 50 per cent of the rated load.

To illustrate the need of proper counterweighting, assume the following problem:

L = rated elevator load..... = 3000 lb.
S = rated elevator speed.... = 500 ft. per min.
W = over-counterweight in lb. = ?
E = per cent efficiency—Line to load.

$$\text{Then, h. p. required (theoretical)} = \frac{(L - W) \times 500}{33{,}000 \times E}$$

If there is no over-counterweight it will require $45\frac{1}{2}$ h. p. (at 100 per cent efficiency) to lift the full load at full speed. At 50 per cent over-counterweight, it will require just one-half of this power. However, with more than 50 per cent, it will take more power to lower the empty car than to hoist the maximum load.

If the over-counterweight is made equal to the average load, the maximum operating efficiency is obtained.

The "line of load" efficiency varies from about 40 to 75 per cent depending upon the size and design of motors, machines and roping. For instance a worm-gear machine with a low gear tooth pitch and with babbitt bearings may not show a greater efficiency than 50 per cent, while a high-speed geared elevator with a high gear tooth pitch, roller bearings throughout and no idler sheaves, may show an efficiency close to 75 per cent.

Cable Compensation. As a rule the compensating of hoisting cables in buildings of ten stories or less is

not an item. Above ten stories however, it is usually desirable to use some form of compensation to prevent the inequality of load on the motor due to the position of the car. The simplest form of compensation consists of wire cables of the same number and size as the hoisting cables connected to the bottoms of the car and the counterweight and passing over idling sheaves in the pit. Chains are often used in place of cables for cable compensation.

Conclusions

The desirable features are safe, smooth and quiet operation, ability to lift the required loads, no heating above Underwriters requirements, continuity of service, low maintenance costs and low power consumption. To obtain the lowest possible maintenance cost and power consumption, the first cost must necessarily be relatively high, so it is important to consider the frequency of duty demand in order to determine which to sacrifice in making an installation.

III.—THE ELEVATOR MOTOR

Power Required

In the application of the electric motor to elevator service, it is first necessary to determine what power is required to drive the elevator. This depends upon the net load to be lifted, the car speed and the various friction losses.

The static friction is unavoidably great, it being necessary in some cases to apply two and one-half times full-load running torque in order to start hoisting the fully loaded car.

The following formula will give the horse power required at full speed with full load on the car. The motor losses are included in this formula. Therefore h. p. = the horse power input to the motor. To get the horse power motor rating multiply h. p. by the motor efficiency.

$$\text{h. p.} = \frac{L \times S}{33{,}000 \times E}$$

where L = Net load in pounds.
S = Full speed of elevator in ft. per min.
E = Overall efficiency.

The line to load, or overall running efficiency of an elevator varies from about 40 to about 75 per cent, depending upon the type, design and construction of the motor, controller, machine, guides, etc. (See "Counterweighting" above).

If the efficiency is known, the above formula may be depended upon to accurately give the horse power rating of the motor for operating the car at full speed with full load. On direct current where, within reason, the available starting torque is a function of the inrush current the size of motor derived from the formula can be depended upon to start the load from rest.

On the other hand, the available starting torque of alternating-current motors is a question of inherent design, and all motor builders do not build their a-c. motors for the same percentage of full-load torque for starting, so it is desirable that these motors be checked on a torque as well as on a horse power basis.

The difference in treating this matter of torque and horse power by different manufacturers of motors has proved confusing. It is therefore of interest to know that the Electric Power Club has taken the subject in hand and is now working out standard ratings which it is hoped all motor manufacturers will adopt.

If a specific installation has an overall running efficiency of 50 per cent and it requires two and a half times full-load running torque of the motor in order to start the maximum rated load in the hoisting direction, the starting efficiency will be only 20 per cent.

After any gear-driven machine starts there is usually a decided increase in efficiency of the gearing owing to the oil film which rotation effects between the gears. Also on all types of elevator machines the efficiency increases after starting due to the oil film which rotation automatically places between the bearings. Therefore, immediately after starting there is an excess of torque which becomes available for acceleration. The amount of this torque depends first, upon the excess motor torque that is provided over and above that actually required to start the machine in motion, and second, upon the excess in elevator starting efficiency over and above the assumed 20 per cent.

In the following formula for the determination of torque required to start an elevator, the starting efficiency has been assumed at 20 per cent as outlined above. If this efficiency in any case is lower, the elevator will not start with the torque as derived by the formula. If the efficiency is greater and allowance is not made in the formula, the derived torque may be so great that the start will be abrupt unless some control arrangement, external to the motor, is included to reduce the initial torque.

$$T = \frac{5252 \times L \times S \times 2\frac{1}{2}}{33{,}000 \times 0.5 \times \text{r. p. m.}}$$

$$T = \frac{0.8 \times L \times S}{\text{r. p. m.}}$$

where T = Torque in pounds at one foot radius on the motor shaft.
L = Net load in pounds.
S = Full speed of elevator in ft. per min.
r. p. m. = Full-load speed of motor selected.

Really, instead of using the formula it would be better to actually test the pounds of torque required. Obviously this is not often possible.

General Motor Characteristics

Elevator motors should have the following characteristics:

1. Good speed regulation under varying load conditions.

2. High starting torque.
3. Relatively low inertia.
4. Quiet operation.
5. Adequate thermal capacity.

An elevator load varies from full positive or even 10 to 25 per cent positive overload to a negative or overhauling load. Good speed regulation is therefore an important consideration. A good many elevators are sold on the basis that they will develop a certain speed with a given load but that they will be capable of lifting a heavier load at a somewhat reduced speed. It is very important that the speed should not increase materially over rated speed in lowering a heavy load. If an elevator is operating at 600 ft. per min. under normal load conditions and it should lower the maximum load at full speed much in excess of this, it might trip the car safety guide grips.

The necessity for a high starting torque has already been outlined.

Because of frequent starts and stops and the necessity for a quick "get away" and rapid slow-down at landings, the inertia of the revolving armature or rotor should not be excessive. This means a relatively small diameter armature with not too much weight in its makeup, and revolving at reasonable speed. For passenger service about 900 rev. per min. is the usual maximum, although no definite limitation can be made, as there are successful elevator installations where the motors run as high as 1800 rev. per min. These however are usually the smaller, low-speed elevators.

While increased flywheel capacity of the revolving armature or rotor undoubtedly increases the power consumption, and therefore is objectionable, on the other hand, it is of advantage in preventing sudden variations in speed of the elevator car. A large flywheel capacity in the rotor of an elevator motor makes it difficult to obtain a rapid variation in acceleration or retardation and therefore makes for greater comfort to the passengers. It is best to strike a happy medium between comfort, speed of acceleration and operating efficiency.

Quiet motor operation is essential on practically all passenger installations and on many freight jobs also.

Because of the extreme differences in service and the great variety of load conditions encountered in electric elevators, it is impossible to establish any standard duty cycles for this service. It has been found that motors designed for a 15- or 30-minute intermittent rating will take care of most installations. A 15- or 30-minute rating means that the motor will carry its specified load for the specified period of time, starting cold, without exceeding the guaranteed temperature rise.

Direct-Current Motors

Most direct-current motors, whether shunt or compound wound have suitable commutating pole windings so as to insure sparkless commutation in both directions of rotation. The commutation should be such that with heavy momentary overloads at starting and during dynamic braking, the commutator will remain in satisfactory operating condition without need for frequent attention.

Direct-current motors are of two general types, single-speed and adjustable-speed, the latter having speed control by shunt field variation. For low-speed, heavy-duty service the motor is usually compound wound to produce sufficient starting torque. The compound winding should represent from 10 to 25 per cent of the total ampere turns on the main poles of the motor, *i. e.*, disregarding the commutating pole windings. The compound winding should be cut out of circuit after starting so as to insure more constant speed characteristics. To reduce the speed to insure accurate stopping, it is necessary to insert resistors both in series and in parallel with the armature. This means inefficient starting and stopping and increases the power consumption materially, as the number of stops per car mile increases. The parallel resistor is also used to secure dynamic braking in the off position.

The adjustable-speed, shunt-wound motor, usually having a speed range of two-to-one or more by shunt field control, provides ample starting torque without a compound winding. For high-speed installations, if this type of motor is used, the elevator can be run at full field speed practically as efficiently as at high speed. In transferring from high to full field speed the motor acts as a generator and returns current to the line. The amount of this returned current has been found from actual test of a three-to-one motor to equal 10 per cent of the total power consumption on an elevator making 150 stops per car mile. For slowing down from full-field to "drag" speed, series-parallel resistor connections are used, but the horse power is only a fraction of that at high speed, so that a saving of power at drag speed is realized over power used in slowing down a single-speed motor. Should anything happen to the armature shunt contactor or to the armature shunt resistor circuit the operator can always slow down to full field speed and make a safe stop without dynamic braking. One thing against the two-speed motor is that for the same horse power and speed it must be somewhat larger and more expensive than a single-speed motor. It is highly important that the two-speed motor be designed to provide stable speed conditions when running with a weakened field.

Alternating-Current Motors

These are of two general types of a-c. motors, the high-torque squirrel-cage induction motor and the slip-ring, wound-rotor induction motor. The squirrel cage motor is used extensively up to about 20 h. p. because of its simplicity and because it only requires a relatively simple form of controller as it is generally thrown across the line with no starting resistor.

When the installation is such as to require a smooth start, a resistor or reactance is placed in the motor primary circuit and gradually cut out after starting.

The last method of starting has been applied to motors as large as 50 h. p. with success. However, it has one disadvantage in that its speed regulation is poorer than that of a wound-rotor motor. While this is of little moment for the lower-speed elevators, it may not be satisfactory on the higher-speed cars. It is of interest to note that this regulation is not as bad as that of a hydraulic or a steam elevator. In actual service the power consumption of the squirrel-cage motor is slightly higher than that of the slip-ring machine, but due to the lack of slip-rings and fewer controller parts it is somewhat more reliable. The slip-ring motor for the same rating is more expensive and has a somewhat lower power factor than the squirrel cage motor.

The slip-ring wound-rotor motor is a standard product and has been used practically as long as electric elevators have had alternating current drive. It has a higher full-speed running efficiency because the resistor in the rotor circuit is cut out by the controller after the motor starts. Its disadvantages have already been outlined.

Single-speed alternating-current motors cannot ordinarily be applied to elevators running faster than 200 ft. per min. because no slow-down can be obtained under the varying load conditions met with in elevator service, and no dynamic braking is available to assist the mechanical brake in bringing the elevator to rest. This means therefore, that the mechanical brake must be depended upon satisfactorily to stop the car from the full running speed. This is a difficult problem. The energy stored in the moving mass is proportional to the square of the velocity. The mechanical brake is capable of absorbing this energy only in direct proportion to the velocity, while a dynamic brake will dissipate this energy in proportion to the square of the velocity. The dynamic brake, unavailable with alternating current, is an important adjunct in assisting the mechanical brake for quick, smooth stopping of the elevator. While the development of the two-speed alternating current elevator motor is still in its infancy the demand is so great that rapid perfection of this type of motor for passenger elevator needs is to be reasonably expected. Alternating-current motors are very reliable, and alternating current is daily coming into wider commercial use, so it is quite essential that drastic efforts be exerted along these lines.

The available two-speed alternating-current motors today generally have two primary windings, although some motors are manufactured with but one primary winding which is re-connected to give a range in speed control.

In the two-winding type of motor the connections are usually so arranged that the speed of the motor can be changed without disconnecting the motor from the supply circuit, so that the motor is at all times operating under a positive torque and there is therefore no danger of losing control of the load.

Two-speed a-c. motors are built in both the squirrel-cage and wound-rotor types. The wound-rotor, two-speed motors have two secondary windings. Most of them have five slip rings so as to get the advantage of independent accelerating adjustments for the two windings. There seems to be a tendency toward the straight two-primary winding, squirrel-cage motor which is simpler and which has been found to give even smoother and quieter operation than the other type. Most two-speed motors have three to one speed range. Advantage is taken of the fact that in changing connections from the high- to the low-speed windings, with the car running at full speed, the low-speed winding acts as an induction generator, giving a very powerful slow-down action. This change is somewhat difficult to control smoothly under varying load conditions.

Some manufacturers, in order to get positive speed control with alternating current are using two motors of different rated speeds, both of which are direct connected to the elevator machine. This scheme permits the use of a squirrel cage motor for the low-speed member and a slip-ring motor for the high-speed member. With this arrangement it is possible to obtain the advantages of lower slip and higher operating efficiency which are characteristic of the slip-ring motor. Another point in favor of the two-motor arrangement is that the windings are in the usual form with which all repairmen are familiar and therefore the chances are that quicker repairs can be made. Also equipments have been built consisting of two distinct motors, both in one motor frame.

The two-speed alternating-current motor is being successfully used with car speeds as high as 350 ft. per min. Further development will undoubtedly increase this maximum.

(To be continued)

MANUFACTURERS FOSTER EMPLOYEE EDUCATION

Most progressive manufacturing companies realize that it pays to help educate the employee. Ambition and the will to learn can in many cases be fostered or stifled just as the powers-that-be see fit. Personal initiative and the mental improvements among the workers of the Western Electric Company have always been aided by special training courses, extension schools, and employee scholarships at some of the country's foremost universities, notably Columbia.

This year, the ninth in the history of this company's special evening classes, has broken all attendance records. More than 2000 employees are registered in the educational courses being conducted at the many branches of the company throughout the country. What makes the figures particularly interesting is the fact that attendance at the schools is voluntary.

The Edison Effect and its Modern Applications

BY CLAYTON H. SHARP
Fellow, A. I. E. E.
Technical Director, Electrical Testing Laboratories, New York, N. Y.

WE are so accustomed to thinking of Thomas A. Edison as the father of the incandescent lamp and of the electric lighting industry that we sometimes forget that his first achievements were in the field of the electrical communication of intelligence, and that in this field he is no less distinguished. To say nothing of his inventions in multiplex and automatic telegraphy, it is well to recall that the field of telephony owes no less to the fundamental inventions of Mr. Edison than to those of Alexander Graham Bell. Bell, it is true, invented the telephone receiver of today, but Edison invented the transmitter, and afterwards invented a highly efficient receiver on a principle entirely different from that of Dr. Bell's.

The art of the mechanical reproduction of sounds is based on a fundamental discovery which, to the writer's mind at least, exemplifies the scientific insight and intellectual audacity of Mr. Edison far more brilliantly than anything that he has done in the lighting field. It may be said that a trained physicist would scarcely have been tempted to waste his time in making an experiment so foredoomed to failure as that which Mr. Edison tried and from which the phonograph and the whole phonograph industry as it exists today resulted. Mr. Edison had through his long experimentation a better conception than the physicists of the character and magnitude of the forces brought into play when sound waves set a diaphragm in vibration, and hence his phonograph experimentation was not a piece of foolishness or a piece of luck but the result of reasoned analysis of facts which Mr. Edison himself had gathered through his previous work.

Quite comparable in importance with the above is the moving picture which has given rise to an industry of enormous financial and sociological importance and of which also Mr. Edison was the progenitor.

Thus, without considering his manifold other activities, such as his pioneer work on electric railways, his ore milling processes, his alkaline storage battery, his improvements in cement manufacture, etc., we have a picture of his paternal relationship to three great industries other than electric lighting; namely, those having to do with the transmission of speech, the reproduction of speech and the pictorial reproduction of objects in motion.

By some professional physicists and by certain others, Mr. Edison has been reproached as being a pure empiricist. He has been considered to have tried everything, possible and impossible, and as a result of countless experiments made by the hands of many able assistants, to have stumbled upon a number of important discoveries, which with a keen commercial instinct he has exploited to the limit. To those who are familiar with Mr. Edison's powers of insight and deduction this charge needs no refutation, but it is interesting in this connection to recall a discovery of his which has been acknowledged by the physicists as a discovery appertaining to the field of pure physics. This is the phenomenon which has long gone by the name of the "Edison Effect." The discovery of this effect came as a by-product of Mr. Edison's work in investigating the peculiarities and behavior of the incandescent lamp, which had led him into the study of the physical and chemical actions which take place in highly evacuated glass bulbs containing a glowing filament. That it was a by-product of this other work no more detracts from the value or merit of the scientific discovery than does the fact that Roentgen's discovery of X-rays was incidental to other experimental work which he was doing.

By an "effect" physicists have long designated phenomena or groups of phenomena which are new in themselves and which fail to arrange themselves into any given theoretical classification or to admit of an explanation under existing theories. Thus we have in physics a large number of effects (to which have been given the names of their discoverers, all of whom have been distinguished in the field of pure science), such as for instance, the Peltier effect, having to do with the absorption and evolution of heat at the junction of two metals carrying a current; the Thomson effect, having to do with thermoelectric currents in a given metal; the Hall effect, having to do with the deviation of currents in a thin film under the influence of a powerful magnetic field; the Purkinje effect, having to do with the variation of sensibility of the eye for the red and the blue ends of the spectrum with high and low illumination; the Zeeman effect, having to do with the displacement of spectral lines when a radiating gas is submitted to a powerful magnetic field, etc. Of all these effects none has been so prolific in practical consequences as the Edison effect.

The earliest carbon incandescent lamps as well as all of their successors have been subject to discoloration or blackening of the bulb by an opaque deposit thereon. This bulb blackening was very naturally a challenge to Mr. Edison. In the course of his investigations of it, he noticed that frequently there was on the bulb in the plane of the filament, a line which was not blackened, something which looked like a shadow of one leg of the filament. Furthermore he found that the leg which cast the shadow was always the one connected with the positive side of the circuit. It appeared as if the negative leg of the filament were throwing off minute carbon particles which

traveled past the positive leg and deposited themselves on the glass everywhere excepting directly in the line of or behind the positive leg. In further investigation

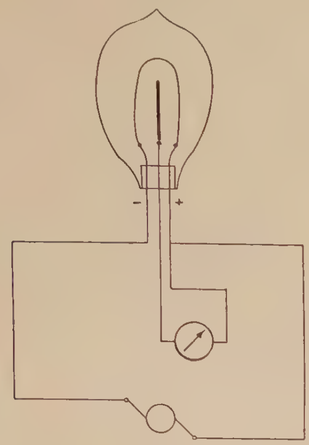
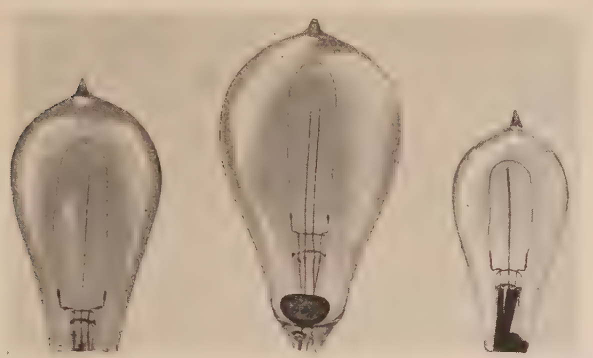


Fig. 1—Circuit for Demonstrating Edison Effect

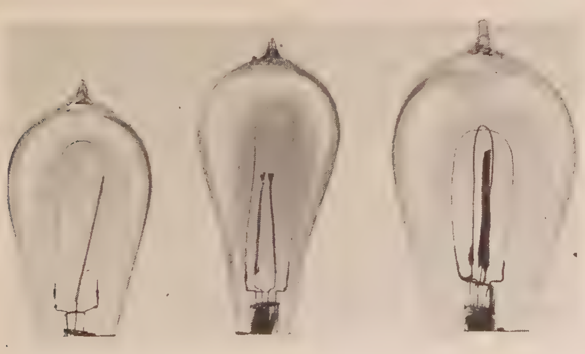
of this phenomenon he made lamps with wires and with plates set up between the two legs of the filament with wires brought out from them to permit



16-c. p. 110-volt, bamboo filament with single wire. 1884.

Replica of double-wire lamp. 1904.

10-c. p. filament with single plate of platinum foil. 1884.



16-c. p. filament with single plate of platinum foil. 1884.

16-c. p. filament with two plates of platinum foil. 1884.

Two bamboo filaments crossed with single plate platinum foil at center. 1884.

Fig. 2—Edison Effect Lamps

the determination of their electrical condition. With arrangements of this kind he found that when he connected such a plate or wire through a galvanometer to the positive leg of the filament, as shown in Fig. 1, a current passed through vacuum or rarified atmosphere of the lamp and affected the galvanometer. If the terminal were connected to the negative leg of the filament, no such current passed. This is the Edison effect discovered by him in 1883. Some of the original lamps which were the subjects of Mr. Edison's investigation are shown in Fig. 2.

The effect was described as follows in a patent specification filed by Mr. Edison on November 15th, 1883.

> I have discovered that if a conducting substance is interposed anywhere in the vacuous space within the globe of an incandescent electric lamp, and said conducting substance is connected outside of the lamp with one terminal, preferably the positive one, of the incandescent conductor, a portion of the current will, when the lamp is in operation, pass through the shunt circuit thus formed, which shunt includes a portion of the vacuous space within the lamp. This current I have found to be proportional to the degree of incandescence of the conductor or candle power of the lamp.

In response to an inquiry as to the line of experimentation on which he was engaged in 1883 when he discovered the Edison effect, and the line of reasoning which led to the experiments in which he inserted dead electrodes of wires and plates in the lamps, Mr. Edison prepared a written statement under date of September 2nd, 1921 for use in connection with this paper. He states:

> As to the "Edison Effect" let me say that I was investigating to find the reason why such black shadows were cast by the filament. This led to the experiment.
>
> My theory was that the residual gas coming in contact with the filament, and part of the filament itself, became charged and were attracted by the glass and discharged themselves. As the polarity was unchanged I thought this should give a constant current. The extra pole was put inside afterward to increase the current, as my first experiment was with only a piece of tin-foil pasted on the outside of the bulb. This gave a good deflection on the galvanometer. In fact the needle went off the scale.
>
> On putting wires and plates on the inside of the bulb the effect was greatly increased, so much so that at the Philadelphia Exposition I put a telegraph sounder in the circuit and it worked well.
>
> As I was overworked at the time in connection with the introduction of my electric light system I did not have time to continue the experiment.

The name "Edison effect" seems first to have been given to it by William (afterwards Sir William) Preece. After having been shown the effect by Mr. Edison, he investigated it further in some lamps which Mr. Edison had given him and reported the matter in 1884 to the Royal Society of London. He spoke of it at that time as a matter on which Mr. Edison was still working.

The effect was investigated later at some length by Prof. J. A. Fleming who introduced metallic shields around the filament at various places and showed conclusively that the effect was due to projected particles negatively charged quite in accordance with Mr. Edison's earlier belief. The nature of these particles, now known as electrons, was, however, not

understood until modern theories of the conduction of electricity by gases had been developed.

Afterwards Richardson investigated the law of the emission of these electrons from a hot filament and formulated the law according to which it occurs. The final development of the theory has been due to Langmuir, who showed the influence of the "space charge effect."

It is supposed that in the interior of a metallic conductor free electrons exist and that it is the motion of these electrons which constitutes the conduction of current. The electrons are held within the surface of the conductor by some kind of a force which is stronger in some substances than in others. The activity of the electrons is increased by an increase in the temperature of the conductor, so that in a hot conductor there is an occasional very fast moving electron which breaks through the surface and escapes from the conductor as a minute free charge of negative electricity.[1]

If now, no means are employed to carry away the free electrons from the vicinity of the surface of the heated conductor, the repulsive effect of the charge in the vicinity of the conductor retards the emergence of further electrons. Furthermore some of the electrons remaining close to the heated filament are caught within its sphere of influence and return to it. When the rate of return of electrons to the filament is equal to the rate of emission of electrons from the filament, a condition of saturation is reached. If the electrons are drawn away from the surface, other electrons will escape continuously and a current of electricity is set up—a true convection current. In the Edison effect the electrons are so removed by the electrostatic attraction of the positive leg of the filament. Thus there is a current, called a thermionic current, passing from leg to leg of the filament through the vacuous space. The plate inserted between the legs of the filament enables this current to be detected, for the electrons which strike the plate give up their charge to it, so that if the plate is connected by a wire to the positive leg of the filament, a current will flow from the positive leg to the negatively charged plate. Evidently no such current would result from a connection to the negative leg.

The emission of electrons from a conductor under the influence of heat is called thermo-ionization, and the currents so produced are referred to as thermionic currents.

In the foregoing it has been assumed that there are no gas molecules in the evacuated space which can interfere with the electrons emitted by the heated filament. If such gas molecules are present, as they are in what is ordinarily called a high vacuum, the electrons will from time to time collide with such gas molecules and will, if the electrostatic attraction on them has been great enough to impart to them a sufficient speed, strike them hard enough to knock off an electron or two from the molecules collided with. These electrons so set free from the gas molecules, behave like the electrons liberated from the filament, and under favorable circumstances may be much more numerous than the original electrons emitted by the filament itself. The residual gas molecules which, having been deprived of part of their negative electricity, are now positively charged, become gas ions and tend sluggishly to carry a current in the reverse direction.

For a long time it was a debatable question whether the thermionic currents were possible in the absence of all gas from the surroundings of the heated conductor, or whether the currents must not be ascribed to the residual gas present in the bulb. This question was finally answered by Langmuir who evacuated bulbs to a degree unknown before, by absorbing the residual gases in charcoal at the temperature of liquid air. Langmuir showed that the Edison effect occurred in such an ultra-vacuum, but that the amount of current which could be taken from an Edison effect bulb depended very greatly on the speed with which the electrons emitted were continuously swept away under the influence of electrostatic force.

The whole thing is a good deal like ordinary evaporation. We know that from the surface of water, vapor is continually passing off and that the rate of emission of vapor depends upon the temperature of the water. We know that if the water is totally enclosed, the space within becomes saturated with water vapor, so that no more is given off from the surface unless the temperature is raised. If, however, the surface is opened to the air, and the air is caused to pass over it rapidly, as by the use of a fan, the evaporation goes on at a certain definite maximum speed dependent upon the temperature. Furthermore, we know that different liquids evaporate at different rates. So with thermionic currents, the rate of emission of electrons depends upon the temperature, and depends upon the rapidity with which the free electrons are moved out of the way so that they will not impede those which follow them. The movement is caused by an electrostatic field due to a voltage influence between the filament and the plate to which the electrons are attracted. With a given filament temperature the current increases with increases in the electrostatic field until the point is reached at which the filament can produce no more electrons at that temperature, no matter how strong the electrostatic field is, and the current remains constant even though the electrostatic field is increased. Conversely, with a given electrostatic field, the current increases with the filament temperature until so many

1. It had been known before Edison's discovery that certain substances when heated would impart an electric charge to a nearby insulated conductor, and this matter had been studied at great length by Elster and Geitel, who however, did not extend their researches to the phenomena in evacuated bulbs until something like five years after Mr. Edison's discovery.

electrons are given off that the field is incapable of handling them, and a condition of saturation ensues in the space surrounding the filament, so that the current remains constant with increase in filament temperature. If the voltage applied to the plate, however, is increased, the thermionic current takes on a higher value.

In analogy with the evaporation of liquids we find also that different materials differ in their thermionic emission at given temperatures.

The pure metals at a given temperature are far less efficient in emitting electrons than are the oxides of the alkaline metals such as oxides of barium and strontium which Wehnelt showed to have far greater electron emissive power than any of the pure metals, or than carbon.

Few laboratory experiments have had greater and altogether unexpected practical consequences than those of Mr. Edison in 1883. In what follows an attempt is made, through the citation of certain specific examples, to give a picture of some of the developments and present-day applications of the Edison effect. In so doing an explicit disclaimer is made of any intention to attempt to write a treatise on the subject or to make the picture complete. It is hoped, however, that the account given is accurate as far as it goes.

Mr. Edison applied in 1883 for a patent on an electric indicator employing an Edison effect lamp. This indicator was not a practical success because of its inconstancy, which again no doubt was due to the instability of the vacuum conditions in carbon filament lamp bulbs. No practical application was made of the Edison effect until Fleming took advantage of the property of Edison effect lamps of conducting current in one direction while suppressing it in the other; that is, what is known as the rectifying effect, and applied such lamps to the reception of signals in wireless telegraphy. Fleming's work in wireless telegraphy brought him in contact with the fact that the coherer, which was the wireless detector of those days, owed its effectiveness to a similar rectifying or valve action, and so he applied the lamp instead of the coherer to a wireless receiving circuit. As a wireless receiver the lamp was, however, not particularly effective.

It remained for DeForest to make the great step in advance by introducing into the lamp between the plate and the filament a little grid or sieve through which the electrons must pass to the plate, and which could be given an electrostatic charge whereby the rate of passage of the electrons could be controlled. To this device he gave the name of "audion," and to the audion and its related devices under other names, such as the "pliotron," all of which however depend upon the Edison effect, are due the greatest advances in the art of the electrical communication of intelligence at the present time. Capable as it is of operating as a detector or receiver of signals, as an amplifier and as a producer of alternating currents of any frequency, it is a most versatile apparatus.

To understand the action of the three-electrode thermionic tube or audion, consider an evacuated bulb containing a filament heated to incandescence and emitting electrons, and facing the filament a plate which is maintained by a battery at a potential higher than that of the filament. Then the positively charged plate attracts to itself the elementary negative charges of electricity which we call electrons, and a thermionic current is set up which may be detected by a galvanometer in series with the battery. Any acceleration of the velocity of the electron stream increases the current, and vice versa, any slowing down of the rate of flow of electrons decreases the current. Now let us put in the midst of this stream between the filament and the plate a fine wire metallic grid through which under ordinary conditions practically all the electrons pass without interference, and let us by means of a battery or otherwise bring this grid to a negative potential with respect to the filament. The negatively charged

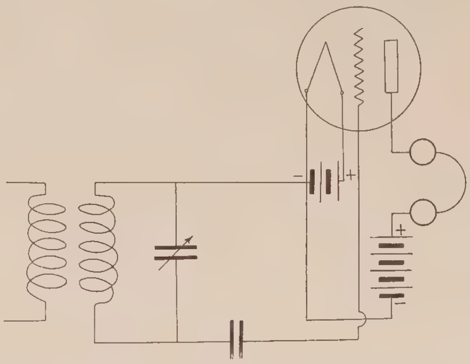


Fig. 3—Detector Circuit for Wireless

grid will repell the oncoming electrons, preventing their free passage, slowing down the stream and diminishing the current. A positive charge on the grid will have the opposite effect; that is, it will cause the current to increase. The charge on the grid required in either case may represent an exceedingly small amount of energy. The thermionic current, however, represents considerable energy, so that we have here a device in which a very small amount of energy controls the rate of expenditure of a very much larger amount.

The method of use of the device in the reception of wireless messages is illustrated in Fig. 3. Here we see that the antenna connections are brought through a primary of an air-core transformer. The secondary of this transformer has in parallel with it an adjustable condenser which is brought to such a capacity that the natural period of oscillation of the circuit is the same as the frequency of the incoming waves. Hereby through the principle of resonance, the maximum voltages are produced. One side of this resonating circuit is connected to the filament of the receiving tube, which filament is brought to incandescence by a few cells of

battery. The other side of the circuit is connected through a small condenser to the grid. The plate is connected to the positive terminal of a battery, which through the receiving telephones is joined to the filament. Without going into details as to the mechanism of reception, it is sufficient to say that the incoming

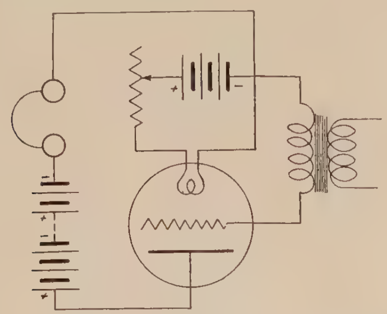


Fig. 4—Amplifying Circuit for Wireless

wave trains acting through the condenser on the grid cause the grid to acquire a negative potential and hence cause a diminution of the battery current passing from the filament through the telephone to the plate, so that for each set of incoming wave impulses, which themselves would be inaudible in a telephone, a signal is heard. The energy represented by the incoming wave train is extremely minute, but as noted above, it alters the flow of energy represented by the plate current and so produces a relatively large effect. This is the three-electrode tube used as a receiver or detector of wireless signals sent out by damped or non sustained oscillations such as are produced by a spark transmitter.

Now if instead of the telephone, the primary of a small step-up transformer is connected directly in the plate circuit, with the secondary of this transformer connected between the grid and the filament of another three-electrode tube, Fig. 4, the signals cause variations in the potential of the grid of the second tube, and these produce larger changes in the plate current of the second tube, so that with the telephone connected in the plate circuit of the second tube, the strength of the signals is greatly increased. This typifies the three-electrode tube used as an amplifier.

The three-electrode tube may be used also as an alternating-current generator for the production of sustained or nondamped waves of all frequencies from one cycle in several seconds to millions of cycles per second. To do this, advantage is taken of the amplifying property of the tube. As has been said, a small amount of energy applied to the grid is able to control a much larger flow of energy in the plate circuit. If some kind of coupling, as by inductance coils or condensers, is made between the grid and the plate circuit, so that some of the energy originating in the plate battery is transferred to the grid in such a way that any oscillation in the grid circuit is helped on and maintained by the more powerful oscillations produced thereby in the plate circuit, the tube can be made to operate as a generator.

A simple form of generator circuit is illustrated in the so-called "feed-back" circuit shown in Fig. 5. It will be seen that this differs from the circuit shown in Fig. 3, in which the tube is used as a detector, only in that a coil in the plate circuit is coupled inductively with the coil of the oscillating circuit to which the grid is connected. If an oscillation is started in the grid circuit, similar and stronger oscillations are produced in the plate circuit. Through the inductive coupling these plate current oscillations reinforce the grid voltage oscillations which govern and control them and through this interaction the process goes on continuously, the source of energy being the plate battery. The frequency of the oscillations depends upon the inductance, capacity and resistance in the circuits, but chiefly on the inductance and capacity in the resonant circuit to which the grid is connected. Many other forms of generator circuits involving different connections of inductances, capacitances and resistances are possible.

One interesting application of the feed-back circuit is in the reception of signals sent out by means of sustained waves. Such waves are generated either by a high-frequency alternator or by a Poulsen arc generator or by three-electrode tubes used as generators. The frequency of such waves is so high that they are inaudible in the telephone and recourse is had to so-called heterodyne reception. The principle of heterodyne reception is as follows: Suppose the sending station is using alternating current of a frequency of 100,000 cycles per second; this gives a wave length of 3000

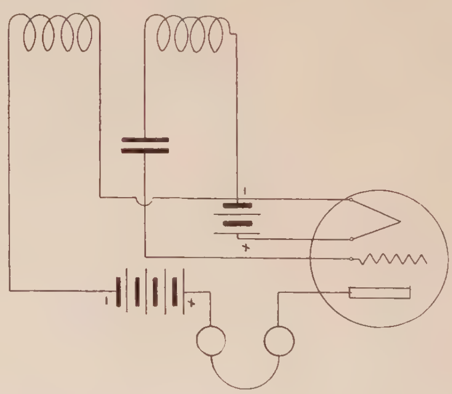


Fig. 5—Feedback Circuit for Wireless

meters. The receiving circuit is tuned to this frequency, but the ear hears nothing. Now, suppose we introduce into the telephone circuit a locally generated alternating current of a frequency of 99,000 cycles per second. The telephone diaphragm will be acted upon by both frequencies and will vibrate strongly when the two currents are in phase with each other and feebly when they are in opposition to each other. These

alternations in phase will occur at a rate equal to the difference in frequency of the two currents, giving rise to the phenomenon of beats. In the case considered, the beat frequency will be 1000 cycles per second, a frequency which gives good audibility. When the sending current is interrupted, the beats no longer occur and the sound disappears. Now, the tube with the feed-back circuit may be used in heterodyne reception, because the tube itself will generate the required local alternating current.

Wireless telephony may be considered to be built up on the basis of the three-electrode tube used in its various capacities. A high-frequency alternating current is produced by a tube used as a generator. The grid is acted upon by the output current of a tube called the modulator tube, the input of which is controlled by a telephone transmitter. Thus the high-frequency currents are varied in amplitude in accordance with the variations in the telephonic transmitter current. The high-frequency currents thus sent out are received by the detector tube at the distant station, and after suitable amplification by tubes used as amplifiers, reproduce the original sound in the telephone receiver. In "wired wireless" the stations are connected by a wire which guides the waves in the ether directly from one station to another with a great gain in efficiency of transmission.

In the foregoing we have considered tubes in which the electron flow from cathode to anode is controlled by electrostatic action. Very recently Hull of the General Electric Research Laboratory has described a tube in which magnetic instead of electrostatic force is used, and to which the name "magnetron" has been applied. In these tubes the anode and the cathode are concentric one with another, and the tube is surrounded by a longitudinal helix of wire through which a current may be passed.

To understand the operation of this device, suppose that the hot filament is in the axis of the tube, and the anode, in the form of a wire cylinder is near the walls of the tube. A battery connects the two, raising the anode to a high positive potential. When the filament is heated, electrons will flow radially from the filament to the anode. Now, if a current is passed through the external helix, magnetic lines of force will pass through the tube parallel with the axis. Under the influence of these magnetic lines, the electrons will be deflected from their radial motion, and if the magnetic field is sufficiently powerful, the electron paths will be curved to such an extent that the electrons never reach the anode, but return to the vicinity of the cathode. When this happens, the flow of current through the device ceases. The effect is very abrupt, for until this critical value of the magnetic field has been reached, all the electrons while pursuing a curvilinear path, reach the anode eventually and the thermionic current has its full strength. When the critical field value has been passed, none of them get through.

Hull points out the possible use of the magnetrons not only as amplifiers and generators in wireless, but also in heavier engineering. He sees an application of them in the protection of machines from surges and from lightning.

Three-electrode tubes, being capable of use in such

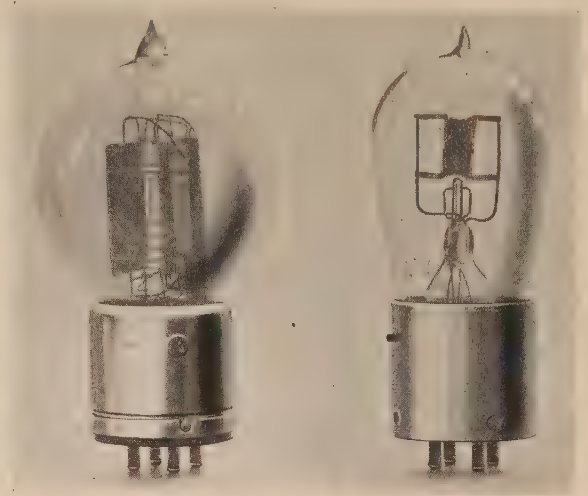


Fig. 6—Western Electric And General Electric Tubes

different capacities, naturally differ in form and size in accordance with the use for which they are intended. They differ also in the degree of vacuum maintained within, the original ultra-high vacuum tube being the "pliotron". Moreover they are divided into two classifications in accordance with the character of the filament which produces the thermionic currents, which are

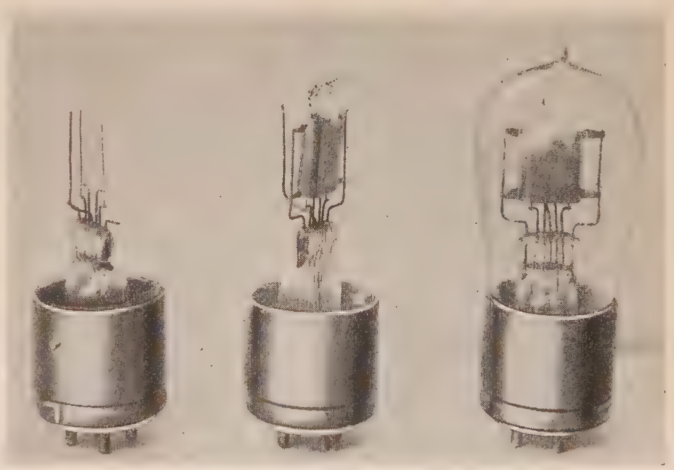


Fig. 7—Pliotron Detector

either of tungsten or of platinum coated with metallic oxides. As has been noted above, the latter type gives off electrons very freely at relatively low temperatures.

Fig. 6 shows side by side an example of each of these types of tubes. The tube in the round bulb is a high-vacuum tube, having a platinum filament coated with rare earth oxides. This general type of tube is

widely used in telephone work as an amplifier. The tube with the straight sided bulb is a high-vacuum, tungsten-filament pliotron. Each of these types contains the filament, the grid in the form of a fine wire, and the plate. The scheme according to which these different elements have been united is so different in the one tube from what it is in the other that the comparison is very interesting.

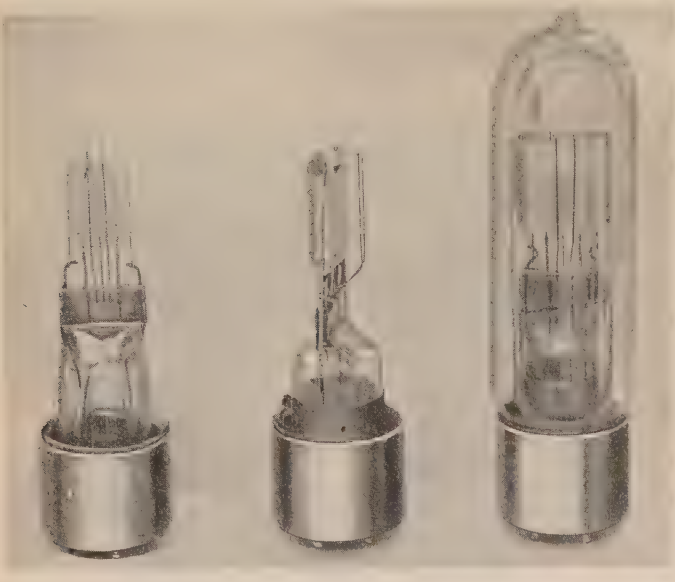


FIG. 8—PLIOTRON GENERATOR—MEDIUM SIZE

Fig. 7 shows a modern detector pliotron having a tungsten filament and a very minute quantity of argon gas within the bulb. The figure illustrates how the parts of the tube are assembled. At the left is shown the stem with the filament and the grid, the latter being a fine wire wound with suitable spacings around two vertical supports. The middle shows the application of the plate which is in the form of a hollow box of elliptical cross-section, closely surrounding the grid. The final assembly is shown in the next part of the figure. The minute quantity of argon is introduced for the purpose of increasing the flow through the tube by the ionization of the gas.

Fig. 8 shows a pliotron generator tube or "dynotron" used for transmitting where outputs of 50 to 150 watts are desired. It will be seen that the construction follows in principle that of the small tube. Where it is necessary to obtain very much power, the form of construction is varied, as will be seen in Fig. 9. In this tube two plates take the place of the hollow elliptical box and the support for the plate is introduced from the opposite end of the tube in order to secure the necessary insulation for the very high voltages applied to the plate in order to obtain large power outputs. The tube illustrated is rated at ¼ kilowatt.

Having now examined very briefly the modern developments of the Edison effect in the art of wireless communication, it may be of interest to know that lamps like Edison's original ones have been experimented with by the writer at the Electrical Testing Laboratories, to see what relationship they bear to the modern three-electrode tube. It was desired to know how these lamps would function when used in circuits such as are employed in modern wireless telegraphy and to find out just how near Mr. Edison was to a fundamental discovery in the wireless art of today. Mr. Edison, as has been said, experimented with lamps with one wire and with two wires; also with one plate and with two plates. For the purpose of this experiment lamps were used containing one wire and one plate located between the legs of the carbon filament as shown in Fig. 10. These lamps were made at the Edison Lamp Works through the courtesy of Mr. John W. Howell, to whom the author's thanks are due. Evidently if we connect the leg of the filament which is nearer the wire to the negative side of the circuit, we have an arrangement in which the wire may be considered as a crude kind of grid and the plate as a fairly good plate. The characteristic curve between the grid voltage and the current flowing between the plate and the positive leg of the filament of several of these lamps was obtained by measurement, and one such curve is shown in Fig. 11. Fig. 12 shows corresponding curves of modern three-electrode tubes. The similarity of the curve is quite striking, but as was to be expected, the single wire makes a very inefficient grid. If the wire were crinkled or if a number of wires in parallel were used, it would

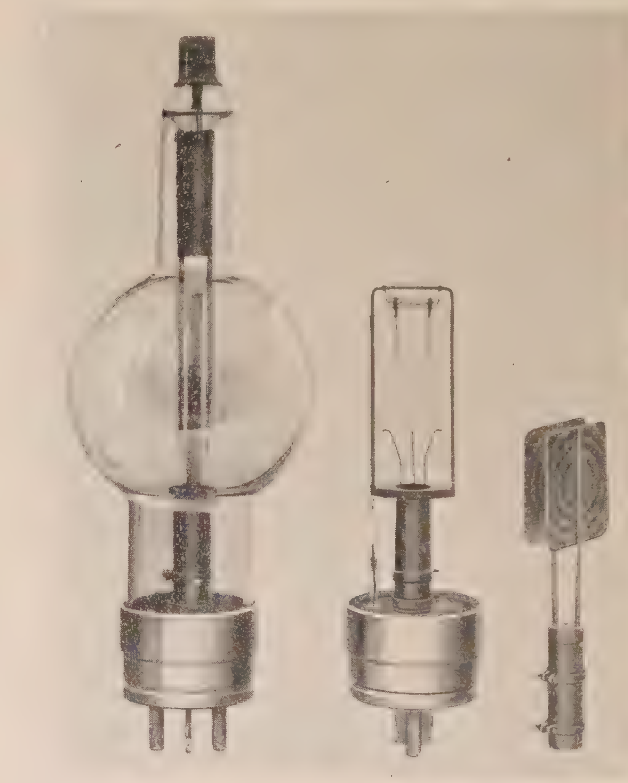


FIG. 9—PLIOTRON GENERATOR—250 WATT SIZE

be much better. However, a lamp of this kind was connected as a wireless detector, the grid wire being connected through a condenser to one side of the oscillating receiving circuit, the other side of which was connected to the negative leg of the filament. The plate was connected directly through a telephone to

Fig. 10—Experimental Edison Effect Lamp

the positive leg of the filament, all as shown in Fig. 13. No plate battery was used. The experiment showed that this made a very efficient form of detector, comparing quite favorably with a modern three-electrode tube

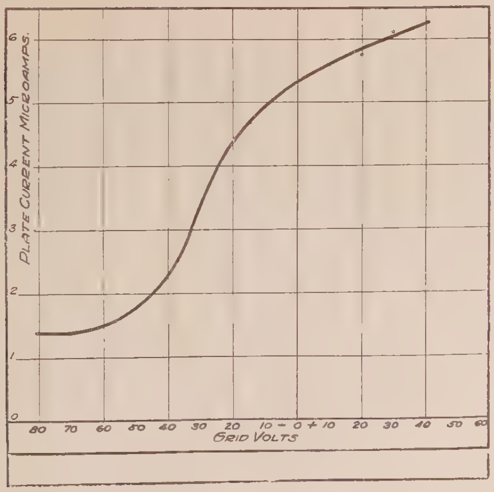


Fig. 11—Characteristic Curve of Experimental Edison Effect Lamp

Thus we find that Mr. Edison not only discovered the Edison effect, upon which more than upon any one thing the modern wireless art is based, but that he actually constructed apparatus which would perform the same as the modern tubes. He made in effect a detector of wireless signals. With slight modifications no doubt his apparatus would act as an amplifier and as an oscillator.

We know now that Langley's original airplane was capable of flying, for when handled in accordance with the aeronautical art as it has been developed since the days of Langley's experiments, it actually did fly over the waters of Keuka Lake. Similarly the Edison

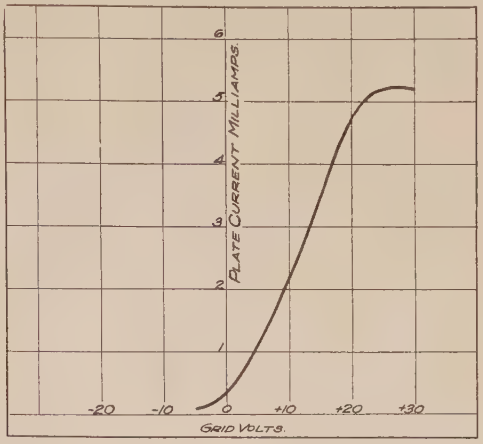


Fig. 12—Characteristic Curve of Audion

effect lamps were capable of use as wireless detectors and when fitted into a modern circuit will operate as such.

While on the subject of the relationship of Mr. Edison's early work to the modern wireless art, it may not be amiss to point out certain other things which he did having a direct bearing on the development of a wireless system. As far back as 1875 he made an experiment in which an electromagnet with an interrupter was connected by a wire to the gas

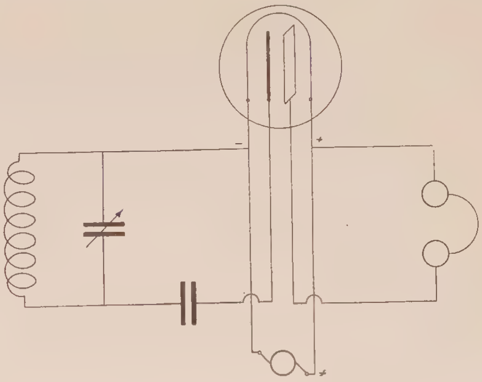


Fig. 13—Experimental Edison Effect Lamp in Detecting Circuit

pipes in the building. By setting up in another part of the building a little dark box containing two conducting points very close together, one of which was connected to the gas pipes, the other being free, minute sparks were observed between the points. Here was apparently a transmission of electric energy in an open circuit. The only way in which the circuit could be closed was through intervening ether, and Mr. Edison with remarkable clearness of vision designated this

phenomenon as a phenomenon of "etheric force." At the time, his etheric force idea was ridiculed by many, but his experiments were confirmed by certain other investigators. They were exhibited amongst others to Sir William Thomson, later known as Lord Kelvin, who recalled them in a discussion before the Institution of Electrical Engineers as late as 1889. They were exhibited at the Paris Exposition of 1881 and were seen by physicists from all over the world.

In 1887, Hertz came out with his discovery of the so-called Hertzian waves, in which he used a high-voltage spark between electrodes to set up sparks between two adjacent metallic points in a dark box, which points were connected to conductors not metallically connected to the high-tension circuit. Hertz's discovery evidently related to the same phenomenon as Edison had discovered many years before and had designated as a manifestation of etheric force, and the apparatus which Hertz used showed a marked similarity to that which Edison had employed and had exhibited in Paris in 1881. Hertz had the advantage that he had an explanation at hand for his phenomenon on the basis of Maxwell's electromagnetic theory. Edison's experiments lacking their theoretical basis at the time they were first made, were never taken very seriously by the scientific world, and fell into oblivion. Concededly Hertz's experiments lie at the basis of wireless transmission. Edison had the same basis many years before.

Furthermore, we know that Edison experimented in telegraphy to and from moving trains and that he expanded his ideas to the extent of applying in the year 1885 for a patent which was granted in 1891, for means of transmitting signals electrically. This patent shows the use of elevated masts carrying condenser surfaces on them for spreading abroad the electrical impulses, and even shows two vessels equipped with the equivalent of modern antennas high on their masts (See Fig. 14) The specification for this patent[2] is wonderfully prophetic. It reads in part as follows:

* * * * * * * *

The present invention consists in the signaling system having elevated induction plates or devices, as hereinafter described and claimed.

I have discovered that if sufficient elevation be obtained to overcome the curvature of the earth's surface and to reduce to the minimum the earth's absorption, electric telegraphing of signaling between distant points can be carried on by induction without the use of wires connecting such distant points. This discovery is especially applicable to telegraphing across bodies of water, thus avoiding the use of submarine cables, or for communicating between vessels at sea, or between vessels at sea and points on land; but it is also applicable to electric communication between distant points on land, it being necessary, however, on land (with the exception of communication over open prairie) to increase the elevation in order to reduce to the minimum the induction-absorbing effect of houses, trees and elevations in the land itself. At sea from an elevation of one hundred feet I can communicate electrically a great distance, and since this elevation or one sufficiently high can be had by utilizing the masts of ships—signals can be sent and received between ships separated a considerable distance, and by repeating the signals from ship to ship communication can be established between points of any distance apart or across the largest seas and even oceans. The collision of ships in fogs can be prevented by this character of signaling, by the use of which, also, the safety of a ship in approaching a dangerous coast in foggy weather can be assured. In communicating between points on land poles of great height can be used or captive balloons. At these elevated points, whether upon the masts of ships, upon poles or balloons, condensing-surfaces of metal or other conductor of electricity are located. Each condensing-surface is connected with earth by an electrical conducting-wire.

Thus we see that Mr. Edison had almost within his hands all the elements of wireless transmission. He had the high-frequency currents, he had the elevated masts and he had the detecting apparatus. It needed only the coordination of these several elements to make the modern wireless system. We cannot but feel sorry that his necessary preoccupation with the electric light prevented him from concentrating his attention upon this other great field, for we cannot doubt that had he done so the wireless art more or less as it is known today would have emerged from Menlo Park.

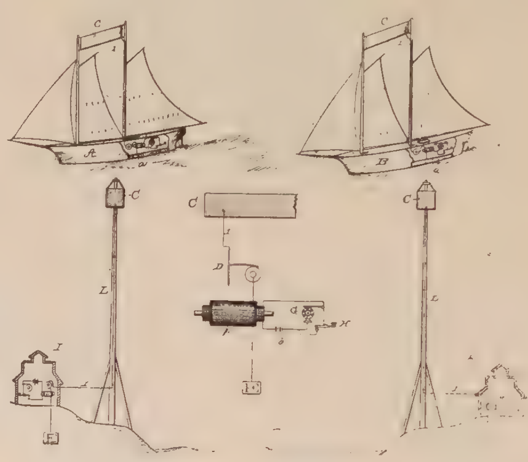


Fig. 14—Edison's Wireless System

It is not in the wireless art alone that the Edison effect has found its application. As has been noted, the Edison effect is essentially a rectifying effect, the electrons which carry the current being produced by a hot filament. Two classes of commercial rectifiers have been made on this principle. The first is known as the "kenotron." The kenotron rectifier as described by Dr. Dushman consists of a bulb containing a tungsten filament as cathode, and facing the filament an anode plate. The bulb is evacuated to an ultra-high vacuum condition. Under this condition no gas molecules being present, no positive ions exist, and the current being carried only by negative electrons, can go in only one direction. Furthermore, because of the absence of gas molecules, very high voltage can be applied between the filament and plate without a

2. This patent was sold in 1903 to the Marconi Wireless Telegraph Co.

breakdown. Hence a kenotron may be used as a rectifier in a high-voltage alternating circuit and will give as its output high-voltage direct current. Direct voltages of 100,000 volts may thus be obtained, a result more or less impracticable by any other form of apparatus. Such high voltages are employed in testing work and in fume or smoke collection by the Cottrell process, and for direct-current X-ray tube operations. Kenotron rectifiers are also sometimes used for furnishing the plate current of pliotron tubes. What fascinating possibilities may lie concealed in the suggested application of the Edison effect to high-tension transmission of electrical energy by rectified alternating current may be judged from the following quotation from Dr. Hull's paper on "The Magnetron."

Fig. 15—Tungar Rectifying Bulb

> One may predict that one year will see these tubes in use as kenotron rectifiers for series arc lighting. Five years will see them in substations replacing synchronous converters. In ten years they will be on electric locomotives, either as rectifiers, allowing the use of d-c. motors or as variable frequency alternators, taking their power from a high-tension d-c. trolley line. Twenty years will see d-c. transmission lines, fed through transformers and kenotrons, at any convenient points, by alternators of any frequency, and tapped by the same tubes acting as magnetron alternators, or some equivalent pliotron or combination vacuum-tube alternator.

The second class of rectifier using the Edison effect is the so-called "Tungar" rectifier, see Fig. 15. This rectifier is used chiefly for low-voltage work such as the charging of storage cells. It is necessary that it should conduct freely with very small potential drop, hence the bulb contains pure argon gas at a pressure of about five centimeters of mercury. This gas is readily ionized by the electrons given off from the heated tungsten filament and the profusion of electrons thus set free gives a path of high conductivity. The filament acts as a cathode and the anode is brought close to it so as to diminish as much as possible the voltage drop.

Another important application of the Edison effect is in the Coolidge X-ray tube, an apparatus which has changed X-ray work from a happy-go-lucky, hit-or-miss sort of operation to a basis of scientific precision. The ordinary X-ray tube is a low vacuum or "gas" tube. It depends for its operation upon the ionization of the residual gas by the high-voltage discharge. The electrons so liberated are then hurled with great velocity under the influence of the electrostatic force against the cathode and so produce the X-rays. Its operation is dependent upon the condition of the vacuum in the tube. With use, the vacuum becomes higher and the tube becomes inoperative, so that it is necessary to provide an auxiliary device whereby a small quantity of gas can be passed into the tube. The character of the X-rays produced varies with the degree of vacuum and with the voltage applied, and the operation of such tubes is more of an art than a science.

In the Coolidge tube, Fig. 16, the electron-producing and electron-hurling functions are separated. The electrons are liberated by the Edison effect, that is, by heating a filament of tungsten. The tube is evacuated to the point where no residual gas is present. Hence the only electrons present are those given off by thermionic action. A high voltage is applied between the filament and the cathode and this voltage serves to drive the electrons to the cathode and so to produce the X-rays. Evidently here is an apparatus in which all the elements are under control, for the quantity of electrons liberated, and hence the strength of the X-rays produced, can be gaged exactly by the temperature of the filament, which is determined by the current through it, while the speed with which the electrons strike the target, and hence the hardness or softness of the rays, that is, their penetrating power, depends upon the high voltage which is applied and which also is under exact control.

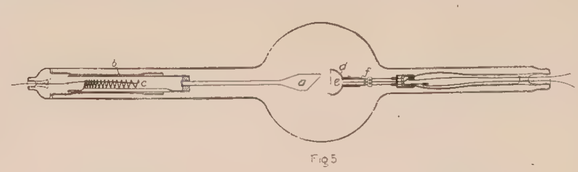


Fig. 16—Coolidge X-Ray Tube

A hemispherical shield surrounds the filament and concentrates the flow of electrons onto the target. The latter is made of massive copper to conduct away the large amount of heat resulting from the electric bombardment, and into the copper is set a piece of tungsten at the point where the electrons strike, so

that there is no danger of melting this portion of the target. The tube acts as a rectifier; hence it can be operated either with high-voltage direct current or with alternating current, for with alternating current the inverse discharges are suppressed.

The original X-ray tube was a Crookes tube, the X-ray effect having been discovered by Roentgen. Improvements which have been made in it are detail improvements only. The Coolidge tube represents a radical departure from the Crookes tube and marks the greatest advance in X-ray science since its inception.

We must not forget, however, in this connection that the fluoroscope, or screen coated with tungstate of calcium fixed in a box which fits about the eyes, and which is used for visual observation of X-ray effects, is also an invention of Mr. Edison's. So that he has contributed not only the Edison effect, on which the modern tubes producing X-rays depend, but also that invaluable apparatus for their visual observation.

Before closing this very inadequate and fragmentary resumè of the modern application of the Edison effect, justice requires that a tribute be paid to two of the great agencies through which these have been carried on. For a large part of the development of the audion, especially of the type with the oxide coated filament, and for its widespread application to telegraphy and telephony, as well as for theoretical and experimental development along other lines, we are indebted to the fruitful labors of the corps of talented scientific men connected with the Research Laboratory of the Western Electric Company under Dr. Jewett, and to the engineers of the American Telegraph and Telephone Company, under Col. Carty. They have performed a magnificent work. For the development of the ultra-high voltage apparatus, as exemplified in the pliotron and the kenotron and the Coolidge tube, credit is due to the Research Laboratory of the General Electric Company, where under the inspiring leadership of Dr. Whitney, physicists and chemists and engineers, men of genius themselves, have produced scientific discoveries and practical applications almost revolutionary in their character. It is particularly gratifying that these developments from the scientific "effect" which he discovered and which bears his name have come now when Mr. Edison is able to see the field which he opened up yield such rich fruits under the hands of able successors.

The *Electrician*, of London, recently published a "diamond jubilee" issue in celebration of its 60 years of publication. It first appeared on November 9, 1861 and in its 60 years of life has recorded most of the epoch-making inventions in the various fields of applied electricity. Its anniversary issue contains messages of congratulation from Thomas A. Edison, Sir Oliver Lodge and other eminent scientists, and also contains interesting historical accounts of the application of electrical energy to various industries.

COPPER IN 1921

The smelter production of copper in 1921 from ore mined in the United States, as shown by the actual production for the first eleven months and by estimates made by smelting companies for December, was about 461,000,000 pounds, according to a report by H. A. C. Jenison of the United States Geological Survey, Department of the Interior. The refinery production as similarly shown was about 601,000,000 pounds from domestic material and about 320,000,000 pounds from foreign material.

According to the records of the Department of Commerce the total imports of copper for the first eleven months of the year in ore, concentrates, matte, blister, and refined copper were about 318,000,000 pounds, of which about 68,000,000 pounds was refined copper and 157,000,000 pounds was blister copper. The exports for the first eleven months totaled about 567,000,000 pounds, of which about 538,000,000 pounds was new refined copper and 29,000,000 pounds was manufactured—wire, rods, pipes, tubes, sheets, etc.

The total new supply of primary refined copper for the year was about 989,000,000 pounds, which includes refined copped produced from foreign and domestic material as well as imported refined copper. The stocks of refined copper in the hands of domestic refineries on December 31, 1921, excluding those in transit, as estimated by the refining companies, were about 496,000,000 pounds. The stocks of blister copper on December 31, 1921, including material in process, in the hands of smelters, in transit to refineries, and at refineries were estimated by refining and smelting companies at about 297,000,000 pounds.

The quantity of primary refined copper withdrawn on domestic account during the year was about 572,000,000 pounds, calculated as follows:

	1920	1921
Refinery production from domestic sources	1,182,000,000	601,000,000
Refinery production from foreign sources	344,000,000	320,000,000
Imports of refined copper	109,000,000	75,000,000
Stocks of new refined copper Jan. 1	631,000,000c	659,000,000
Total available supply	2,266,000,000	1,655,000,000
Exports (exclusive of manufactured copper)	553,000,000	587,000,000
Stocks on hand December 31	659,000,000	496,000,000
	1,212,000,000	1,083,000,000
Total withdrawn on domestic account	1,054,000,000	572,000,000

The domestic imports and exports of primary refined copper in December, 1921, are assumed to be equivalent to the average monthly imports for the first eleven months. Disregarding the imports and exports for December the quantity of primary copper withdrawn on domestic account would amount to about 614,000,000 pounds.

JOURNAL OF THE American Institute of Electrical Engineers

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Changes of advertising copy should reach this office by the 15th of the month for the issue of the following month

A. I. E. E. Midwinter Convention

FEBRUARY 15-17, 1922

The tenth annual Midwinter Convention of the American Institute of Electrical Engineers will be held in New York City, February 15-17, 1922, in the Engineering Societies Building, 33 West Thirty-ninth Street.

Like the previous midwinter conventions, this will be a working convention devoted chiefly to the presentation of papers and discussions. In addition to the technical program there will be included the presentation of the Edison Medal to C. C. Chesney, as announced elsewhere in this issue, a lecture on some branch of physics, the title and author of which will be announced in the February JOURNAL, and visits to various electrical operating and manufacturing plants in the city and vicinity. The convention will close with a dinner-dance to be held on Friday evening, February 17th. The tentative program is as follows:

Wednesday Morning, February 15

Registration of members and guests.

Wednesday Afternoon

TECHNICAL SESSION

Printing Telegraph Systems Applied to the Handling of Commercial and Railroad Telegraph Traffic, by A. H. Reider.

Modern Developments in Submarine Telegraph Cable Operation, by J. W. Milnor.

Key West—Havana Submarine Telephone Cable System, by W. H. Martin, G. A. Anderegg, and B. W. Kendall.

Wednesday Evening

TECHNICAL SESSION

Condenser Discharge Through General Gas Circuit, by C. P. Steinmetz.

Questionnaire on Lightning Arrester Practise, by F. L. Hunt. (From the 1921 Annual Report of the Protective Devices Committee.)

Deviations from Standard Practise in Lightning Arresters, by E. E. F. Creighton.

Thursday Morning, February 16

TECHNICAL SESSION

Effect of Moisture on Thermal Conductivity of Soils Surrounding Cables, by G. B. Shanklin.

500 *Tests on the Dielectric Strength of Oil*, by J. L. R. Hayden and W. M. Eddy.

An Analytical Investigation of the Causes of Flashing of Synchronous Converters, by E. B. Shand.

Thursday Afternoon

TECHNICAL SESSION

The Use of Superimposed E. M. Fs. and Fluxes in the Solution of Alternating-Current Problems, by V. Karapetoff.

Wave Form and Amplification of Corona Discharge, by J. B. Whitehead and N. Inouye.

Questions on the Economic Value of the Overhead Grounded Wire, by E. E. F. Creighton.

Prevention of Transient Voltage in Windings, by J. Murray Weed.

Thursday Evening.

This session will be devoted to the presentation of the Edison Medal to Mr. Chesney, followed by a lecture.

Friday Morning, February 17

TECHNICAL SESSION

The "Indumore," by V. Karapetoff.

Heating of Railway Motors in Service and on Test Floor Runs, by G. E. Luke.

Also the following papers to be presented by title only:

Skin Effect and Proximity Effect in Tubular Conductors, by Herbert B. Dwight.

Heat Losses in Stranded Armature Conductors, by Waldo V. Lyon.

Current Locus of Single-Phase Induction Motors, by J. K. Kostko.

Polyphase Commutator Machines, by A. B. Field.

Friday Afternoon

The afternoon will be devoted to visits to various plants of electrical engineering interest.

Friday Evening

Dinner-Dance.

This is the first convention to be held under the new ruling of the Board of Directors which prescribes but four general technical meetings of the Institute to be held each year, and owing to the reduced number of general meetings an unusually large attendance is confidently anticipated.

Future Section Meetings

Atlanta.—January 26, 1922. Subject: "Automatic Telephone." Inspection of New Ivy Exchange. Speaker: Under direction of Mr. G. K. Selden, Southern Bell Telephone & Telegraph Company. Place: New Ivy Exchange, 27 Auburn Avenue.

Baltimore.—January 20, 1922, 8.15 p. m., Engineers Club. Paper: "The Use of Electricity for Industrial Heating." Speaker Mr. C. F. Hirshfeld, Chief of Research Department, Detroit Edison Company.

Chicago.—January 18, 1922, 7:30 p. m., Fillerton Hall. Paper: "Radio Telephony." Speaker: Mr. Ralph Bown, of the Department of Development and Research of the American Telephone and Telegraph Company. Following the paper there will be a demonstration of radio telephony and telegraphy

by Mr. R. H. G. Mathews, Director of the Chicago Radio Laboratory.

Cleveland.—January 17, 1922, 8:15 p. m., Club Rooms of the Electrical League, Hotel Statler. Subject: "Refrigeration." Speaker: Mr. A. C. Bishop of A. C. Bishop & Company, Engineers and Architects.

Erie.—January 17, 1922. Subject: "Radio Communication." Discussion led by local authority with demonstration of radiophone transmitter and reception of broadcasting.

Fort Wayne.—January 19, 1922. Subject: "The Heart Throbs of a City." Speaker: Mr. E. L. Gaines. Mr. Gaines is traffic manager of the local Home Telephone and Telegraph Company and will present a very interesting paper to be illustrated by lantern slides. The meeting will be held at the Telephone Company.

Los Angeles.—February 13, 1922. Paper: "The Human Voice and its Electrical Transmission." Speaker: Mr. John Mills, Engineer, Western Electric Company.

Lynn.—January 4, 1922, G. E. Hall, 42 Centre Street, West Lynn. Subject: "Banking." Speaker: Mr. James D. Brennan, Vice-President of the First National Bank, Boston.

New York.—There will be a joint meeting of the New York Section of the Institute and the Metropolitan Section of the A. S. M. E., Friday evening, January 27, 1922 at Institute headquarters, 33 West 39th Street, New York. The subject of the meeting will be "Industrial Power Requirements." Complete details will be furnished the New York membership as soon as available.

Utah Section.—January 27, 1922, Commercial Club, Salt Lake City. Subject: "Possibilities of Electrical Engineering in the Future Development of Utah." Speaker: Mr. Lafayette Hanchett, President, Utah Power & Light Company.

Vancouver.—January 6, 1922, Auditorium, Board of Trade Building, Pender and Homer Streets, Vancouver. Subject: "The Automatic Telephone Isolated Plant as Used by Industrial Plants." Speaker: Mr. F. H. MacGougan.

February 3, 1922, Auditorium, Board of Trade Building. Subject: "Development of the B. C. Electric Railway Company's Hydroelectric System." Speaker: Mr. J. I. Newell.

Washington, D. C.—January 10, 1922. Joint meeting of the Washington Sections of A. I. E. E. and A. S. M. E., to be held in the Department of Interior Building auditorium. The meeting will be preceded by a dinner at the Cosmos Club. Two papers on "Superpower" will be read by Mr. L. E. Imlay and Mr. Henry Flood, Jr., and Mr. N. W. Storer, of the Westinghouse Electric and Manufactur ng Company, E. Pittsburgh, will discuss the subject from a standpoint of "Electrification." The speakers will give a comprehensive review of the superpower scheme from various phases, and the meeting will be of importance to those interested in this subject.

Worcester.—January 19, 1922. Subject: "Superpower. An Answer to the National Power Policy." Speaker: Mr. W. S. Murray, Consulting Engineer, New York City.

A. I. E. E. Directors Meeting

DECEMBER 9, 1921

The regular bi-monthly meeting of the Board of Directors of the American Institute of Electrical Engineers was held at Institute headquarters, New York, on Friday, December 9, 1921, at 3:00 p. m.

Present: President William McClellan, Philadelphia; Past Presidents A. W. Berresford, Milwaukee, Calvert Townley, New York; Vice-Presidents W. A. Hall, Swampscott, Mass., W. A. Del Mar, New York, J. C. Parker, Ann Arbor, Mich., N. W. Storer, Pittsburgh, Robert Sibley, San Francisco; Managers L. E. Imlay, Niagara Falls, Harold B. Smith, Worcester, Mass., James F. Lincoln, Cleveland, R. B. Williamson, Milwaukee, A. G. Pierce, Pittsburgh, H. A. Pratt, New York; Treasurer George A. Hamilton, Elizabeth, N. J.; Secretary F. L. Hutchinson, New York.

A report of the meeting of the Board of Examiners held December 5, 1921, was presented; and the actions taken at that meeting relative to applications for election and transfer were approved. Upon the recommendation of the Board of Examiners, the following action was taken upon pending application: 233 Students were ordered enrolled; 89 applicants were elected to the grade of Associate; 2 applicants were elected to the grade of Member; 8 applicants were transferred to the grade of Member; 2 applicants were transferred to the grade of Fellow.

A petition was presented, signed by ten members of the Institute as required by the Constitution, for the election of Marshal Ferdinand Foch of France as Honorary Member of the Institute; and a resolution electing Marshal Foch an Honorary Member was unanimously adopted. Previous to this meeting the matter had been submitted to the members of the Board and voted upon by letter ballot; and votes in favor of the election of Marshal Foch as Honorary Member had been received from all members of the Board not present at this meeting, thus making it a unanimous vote of the Board as required by the Constitution.

Approval by the Finance Committee of monthly bills amounting to $18,168.39 was ratified.

A list of members in arrears for dues for the year ending April 30, 1921, consisting of 1 Fellow, 29 Members, and 386 Associates, was presented; and the Secretary was authorized to remove the names of these members from the membership list on December 31, 1921, excepting the names of those who request an extension of time.

A report was presented from the Edison Medal Committee announcing the award, on December 8, of the Edison Medal for 1921 to Mr. Cummings C. Chesney, for "early developments in alternating-current transmission."

The following appointments of Institute representatives were made: B. Gherardi, reappointed for term of three years commencing in January 1922, on the Board of Trustees, United Engineering Society; W. I. Slichter, reappointed for term of three years commencing January 1922, on Library Board, United Engineering Society; F. B. Jewett, nominated for re-election by U. E. S. for term of three years commencing February 1922, on Engineering Foundation Board; Harold Pender, appointed for term of three years commencing January 1922, on American Engineering Standards Committee.

Vice-President Sibley made a statement regarding a movement that has been started in the West to bring about the erection of an engineering building in San Francisco, explaining the need for such a building and the steps that have already been taken in the matter—financing, etc., and asked what assistance, if any, the Board of Directors feels that the parent body can render in this matter. It was voted that a committee of three be appointed by the President to investigate the matter and report to the Board of Directors.

Attention was called to the financial difficulty of holding meetings of the Executive Committees of the Geographical Districts; the question of whether or not the Sections should pay the expenses of their representatives to such meetings was raised; and the advisability of making mandatory at least one meeting a year of the Geographical Districts' Executive Committees was discussed. It was voted that the Sections Committee be requested to consider the subject of the conditions under which meetings of the Executive Committees of the Geographical Districts shall be held.

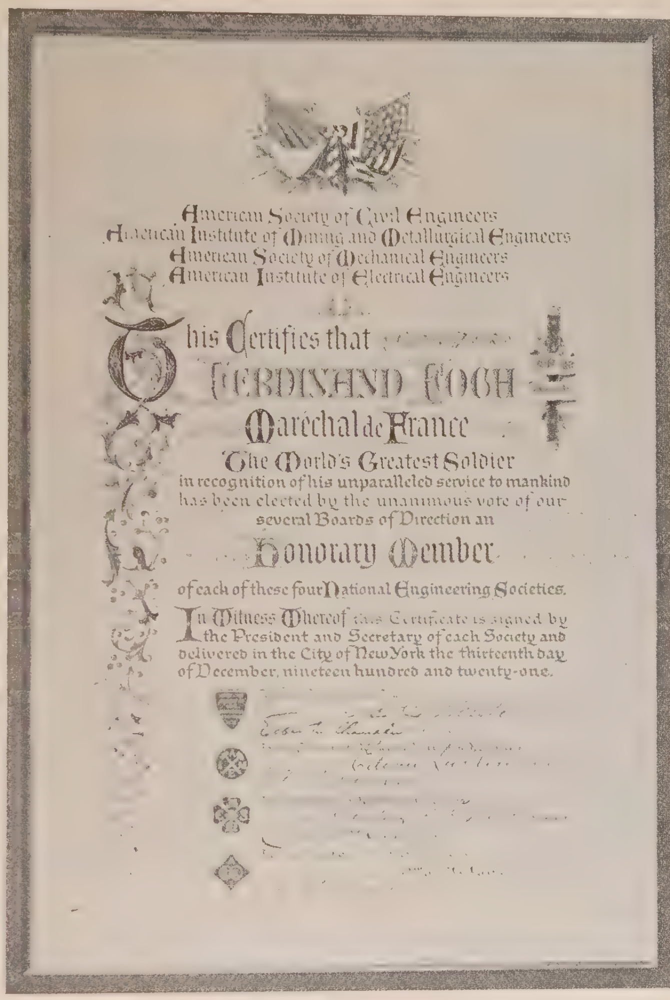
In addition to these actions other matters relating to important activities and the general policy of the Institute were discussed; reference to these matters may be found in this and future issues of the Journal under suitable headings.

Ferdinand Foch, Marshal of France, Honored by American Engineers

ELECTED AN HONORARY MEMBER OF FOUR NATIONAL ENGINEERING SOCIETIES

Marshal Foch, the world's greatest soldier and military engineer, was made an honorary member of the four national societies of Civil, Mining and Metallurgical, Mechanical, and Electrical Engineers on the afternoon of December 13, 1921, at the Engineering Societies Building in New York.

Marshal Foch, on his arrival in the city, went at once to the Engineering Societies Building, arriving there about 3.45 p. m. He was accompanied by a party of about fifty, including fourteen French officers and fifteen uniformed members of the American Legion. The Marshal was met at the entrance of the building by a committee consisting of Alfred D. Flinn, secretary of the Engineering Foundation; Calvin W. Rice, secretary of the American Society of Mechanical Engineers; F. F. Sharpless, secretary of the American Institute of Mining and Metallurgical Engineers; Elbert M. Chandler, acting secretary of the American Society of Civil Engineers, and F. L. Hutchinson, secretary of the American Institute of Electrical Engineers; Charles Warren Hunt and Bradley Stoughton.



CERTIFICATE OF MEMBERSHIP PRESENTED TO MARSHAL FOCH

Some of Those in Attendance

The ceremonies were held in the auditorium. On the platform were the presidents of the four Founder Societies or their representatives as follows: L. P. Alford for Dean Dexter S. Kimball of Cornell, mechanical engineers; George S. Webster, Philadelphia, civil engineers; Calvert Townley, for William McClellan, Philadelphia, electrical engineers; and Edwin T. Ludlow, New York, mining engineers. Others in the platform group were Ambrose Swasey of Cleveland, Commander Legion d'Honneur and founder of the Engineering Foundation; Charles F. Rand, chairman of the Engineering Foundation; Col. William J. Wilgus and Col. A. S. Dwight.

Among the past-presidents of the A. I. E. E. in attendance were T. Commerford Martin, John W. Lieb, Schuyler Skaats Wheeler, Lewis B. Stillwell and Calvert Townley.

Opening Address of Mr. Davies

J. Vipond Davies, president of the United Engineering Society, presided, opening the exercises with the following remarks:

"We have assembled at the call of the Presidents of the Four Founder Societies for a purpose which is unique in the history of our Societies.

"The American Society of Civil Engineers, whose president is Mr. George S. Webster, and secretary Mr. Elbert M. Chandler, the American Institute of Mining and Metallurgical Engineers, whose president is Mr. Edwin Ludlow and secretary Mr. F. F. Sharpless, the American Society of Mechanical Engineers, whose president is professor Dexter S. Kimball and secretary Mr. Calvin W. Rice, the American Institute of Electrical Engineers, whose president is Mr. William McClellan and secretary Mr. F. L. Hutchinson, have an aggregate membership of 45,000 qualified professional engineers, practising in every part of the world.

"These societies represent leadership in the profession of engineering. Their membership stands for the highest ideals, the best practise and for constructive effort.

"By vote of the governing bodies of these societies, taken severally, there has been conferred upon the world's great leader and hero, Ferdinand Foch, Marshal of France, and formerly Supreme Commander of the Allied Armies, the dignity of Honorary Membership.

"This action is unprecedented in that it has been taken at one and the same time and is to be conferred by one instrument. It is epochal to our societies in that it constitutes one more bond of union between the several branches of our profession, as represented by our Founder Societies, and our professional brethren in France.

"On this his first visit to the United States, Marshal Foch, has been able to honor us with his presence, through the courtesy of his host, the American Legion, so as to make this ceremony possible.

"In this our home, the general headquarters of the profession, it is today our honor to receive Marshal Foch."

Address of Colonel Parsons

Col. Parsons then delivered in French the following address:

"Marshal: The art of engineering was defined a long time ago as 'the art of directing the great sources of power in nature for the use and convenience of man.' No better definition can be found today. Of all the sources of power in nature, the greatest, the most valuable, and at the same time the most difficult to direct, is the energy of man himself. He who can direct human energy and turn it to the service of mankind is a great engineer.

"You, Marshal, have directed a greater mass of human energy than any other man has ever done. And you have successfully directed this mass for the highest uses of man, in that you by

its aid have preserved for mankind one of the most precious of human possessions—liberty! Liberty not only for your own illustrious country, but for all the nations of the world.

"The four national engineering societies of the United States now desire to make record of their appreciation of this fact and to convey to you an expression of their most profound admiration for the great leader of men by conferring on you honorary membership in all the societies, the highest honor in their gift and one hitherto never conferred on a single individual.

"Four thousand members of these societies were enrolled in the armed service of the United States, the greater part of whom had the glorious distinction to serve the common cause in France under your orders. They heard the voice and they saw the hand of the master as he led them through battles to victory. Now we desire that you will still continue to lead us, but in peace, by permitting us to inscribe your name at the head of our roll of honor, where it will be, as your deeds have been, an example to us to do better work, and where it will remain forever a noble inspiration for all future generations.

"Marshal, in the name of those members of the societies who served under your orders and particularly in the name of those who fell on the field of honor in France, I salute you!"

Turning to George S. Webster, Col. Parsons said: "Mr. Preident: Ferdinand Foch, Marshal of France, victorious generalissimo of the allied armies in France, stands before you to receive honorary membership in the four national engineering societies."

Mr. Webster then presented to Marshal Foch the certificate of honorary membership, beautifully engrossed, speaking as follows:

Presentation by Mr. Webster

"Ferdinand Foch, Marshal of France, Commander in Chief of the victorious armies of the Allies—master of military strategy—foremost military engineer—the hope of the civilized world during the dark days of the war—idol of the exponents of liberty and justice—military genius whose effective coordination of the armies of the Allies and whose indomitable will inspired them with the hope and the renewed vigor which brought the World War to a successful close!

"In recognition of these achievements and of your unparalleled service to mankind, I have the honor on behalf of the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers, to present to you this certificate of honorary membership, signed by the president and secretary of each society, and also these emblems of membership in the societies."

Marshal Foch responded in a brief speech, which closed the ceremony. The Marshal spoke as follows:

Response of Marshal Foch

"Mr. President: It was due largely to engineering and the engineering industry that the war was brought to a successful conclusion. To the engineering profession also we are indebted for many great lessons which will be vital to mankind in the future.

"The armies could not have done a great deal without the effort of the engineer. Success was made possible to a great extent by the industry of the people at home but when it became a question of decision, when the decisive moments arrived, the engineer stood out as an essential factor in complete triumph.

"What would have become of the armies without the technical training, without the professional knowledge which you have exercised for the Allies and which enabled us to lead our armies in the field, to feed them, to protect them, and to facilitate their advance quickly and decisively?

"It is for these reasons that I am pleased to find you here today, to receive from you so splendid a welcome and to express my gratitude and the gratitude of France, as well as the recognition of my countrymen for the tremendous sacrifices made by you and the men of your calling.

"I am grateful to you for including me in your ranks as a member of the four great engineering societies of the United States. Believe me this honor which you have conferred upon me I indeed appreciate and I shall cherish this event with the happiest memories."

Presidents Presented with Souvenirs

In closing the ceremonies Mr. Charles P. Perrin presented each of the presidents of the four societies with a replica of the medal given to Marshal Foch, saying: "By the courtesy of Mr. Edward Dean Adams, a well-known engineer and life director of the American Numismatic Society, I have the honor to present to each of you gentlemen, in the presence of Marshal Foch, as a souvenir of our celebration today, a replica in silver of the medal of which the Marshal possesses the original in gold."

Report of the American Committee on Electrolysis

The American Committee on Electrolysis has just issued its 1921 report, superseding its preliminary report of 1916. This report embodies such statements of facts and descriptions, and discussions of methods of electrolysis testing and electrolysis mitigation as the members of the committee have been able thus far to agree upon unanimously. In the preface, signed by Bion J. Arnold, Chairman of the Committee, the following statement is made:

> While this report supersedes the preliminary report of 1916, it should, unless the principals see fit to discontinue the work of the main committee, be considered as in the nature of a progress report and not as final, as it is impossible at the present time finally to answer many of the outstanding questions involved. Also it is to be understood that the report is confined to the technical and engineering aspects of the subject and does not attempt to deal with matters of policy or with legal questions, such as the rights and responsibilities of the several interests concerned.

The report comprises five chapters. Chapter One sets forth a rather full statement of principles and definitions. Chapter Two is devoted to a somewhat detailed discussion of the design, construction, operation and maintenance of railways and underground structures affected by electrolysis and to a discussion of questions involving the interconnection of affected structures and railways, ending with a summary of good practise as agreed upon by the committee. Chapter Three gives a discussion of the fundamentals of the whole question of electrolysis surveys, their purpose, scope, possibilities, and interpretation, and also a discussion of the instruments suitable for electrolysis testing. Chapter Four is devoted to an analysis of present European practise relating to electrolysis mitigation. In Chapter Five the committee outlined certain researches which it deems necessary to have carried out in order to make it possible to reach a final solution of some of the fundamental questions pertaining to electrolysis mitigation.

The American Committee on Electrolysis which prepared this report is a joint committee having three representatives from each of the following organizations:

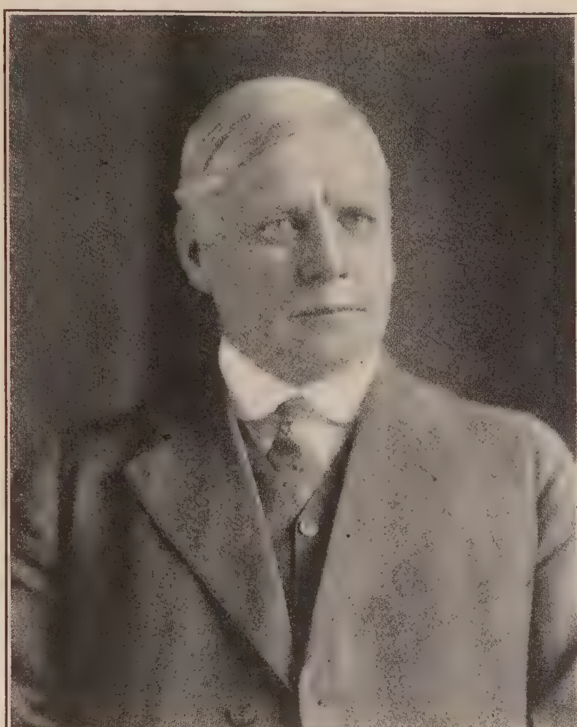
American Institute of Electrical Engineers
American Electric Railway Association
American Gas Association
American Railway Engineering Association
American Telephone and Telegraph Company
American Water Works Association
National Electrical Light Association
Natural Gas Association
National Bureau of Standards.

The report may be obtained from the American Institute of Electrical Engineers, 33 West 39th Street, New York, N. Y. The price is one dollar per copy.

Edison Medal Awarded to C. C. Chesney

The Edison Medal for the year 1921 has been awarded to Cummings Coligny Chesney, "for early developments in alternating-current transmission." Mr. Chesney, chief engineer and manager of the Pittsfield, Mass., works of the General Electric Company, was one of the earliest experimenters in long-distance high-tension transmission, and has since contributed largely to its development.

Born in Selingsgrove, Pa., October 28, 1863, Mr. Chesney was graduated from Pennsylvania State College in 1885, and for three years taught mathematics and chemistry. In 1888 he joined Mr. William Stanley's laboratory force at Great Barrington, Mass., and the following year entered the services of the United States Electric Lighting Company in Newark, N. J., a subsidiary of the Westinghouse Electric and Manufacturing Company. In 1890 he moved to Pittsfield, Mass., where he was one of the original incorporators of the Stanley Electric Manufacturing Company, started with a capital of $25,000. The company was organized to develop the alternating-current inventions of William Stanley, John Kelly and C. C. Chesney. The work was primarily of a pioneer character with little precedent to guide it.



Cummings Coligny Chesney

This company developed the well-known S. K. C. system (Stanley, Kelly, Chesney). The first polyphase transmission plant equipped with the S. K. C. system to be put into successful operation and the first in America was installed in 1893 and is supplying power and light today for use in the towns of Housatonic and Great Barrington, Massachusetts. In 1895 a 12,000-volt plant was installed for service from Lowell to Grand Rapids, Michigan. The operating success of these alternators was due to special design in which the high-tension currents were generated in the stator element by the revolving rotor, these being the first alternators to produce a true sine wave. As early as 1896 alternating-current generators of 6000 volts with control equipment were put into successful operation on the transmission line of the Montmorency Electric Power Company, Quebec. In 1898 generators up to 12,000 volts were placed in service. During the early period two-phase alternating-current induction motors were developed, electrostatic condensers at 500 volts and electric transformers of 100-light capacity. In developing the transformer all spaces in the coils were filled with Gilsenite to provide better heat dissipation and insulation. This occurred as early as 1892, as did the development of cloth treated with oxidized linseed oil. The most effective general insulation in use today was developed by the Stanley Company, in 1891-1892, superseding the old insulating methods using shellac and P. & B. paint. In 1893 belt-driven alternators were put into successful operation and in 1899 alternators of this design direct-connected to steam engines went into successful operation in the power house of the Staten Island Electric Company. These were the first alternators to be operated in parallel and in regular commercial service. Switchboard instruments, high-tension arc breaking devices, frequency indicators, indicating wattmeters, lightning protection for high and low-tension currents, condensers, etc., were among other apparatus manufactured by the Stanley Company. The company built the first revolving field types of alternators used in America. These were extensively used in hydraulic stations, notably the Bay Counties and Standard companies' lines in California, at that time the longest high-voltage lines in the world, using 40,000 to 60,000 volts.

Mr. Chesney was vice-president and chief engineer of the Stanley Company from 1904 to 1906. On the latter date he took up the duties of chief engineer and manager of the Pittsfield works of the General Electric Company, which company had acquired the Stanley Manufacturing Company. Under Mr. Chesney's supervision the Pittsfield works in recent years have made particular progress in the development of apparatus for commercial service up to 220,000 volts, and lately have completed successful tests of 1,000,000 volts for transmission purposes.

Mr. Chesney is a Fellow of the Institute, and has taken an active interest in its affairs. He served as manager from 1905 to 1908 and as vice-president from 1908 to 1910. He is also a member of the Society of Arts, London, of the American Society for the Advancement of Science and of the Engineers Club of New York. During the year 1920 he was president of the Engineering Society of Western Massachusetts. He has always had a strong civic interest, taking an active part in the life of his community. He is chairman of the industrial committee of the crippled children's home in Pittsfield, one of the best equipped industrial rehabilitation schools for children in New England; and is director of the Agricultural Bank and president of the Morris Plan Bank of Pittsfield.

The Edison Medal was founded by the Edison Medal Association, composed of associates and friends of Mr. Thomas A. Edison, and is awarded annually by the Edison Medal Committee of the A. I. E. E. for "meritorious achievement in electrical science, electrical engineering, or the allied arts." It is a fitting tribute to Mr. Chesney for his able work and noteworthy accomplishments in electric power transmission.

The medal will be presented to Mr. Chesney at a session of the Midwinter Convention of the Institute, as announced in the program printed elsewhere in this issue.

The Annual Meeting of the American Society of Mechanical Engineers, held in New York City, December 5-9, 1921, was one of the most successful in its history. Election of officers for the coming year took place at the meeting. The technical sessions were full of interest and profit. Keen interest in the Federated American Engineering Societies was displayed in various discussions by members of the A. S. M. E.

American Engineering Council

WASHINGTON MEETING, JANUARY 4-6, 1922

The next meeting of the Council, to be held in Washington, D. C., will start on January 4 at 2 p. m. with a session of the Executive Board at the Cosmos Club. On January 5 an all-day session of the Council will be held, Dean Cooley presiding. Another business session will be held on the morning of January 6, and on the afternoon of that day there will be a meeting of the Executive Board, the new members of which will be elected by the delegates from the national organizations and the regional areas. The business of the sessions will include election of new officers, proposed constitutional changes, presentation of reports, and plans for the coming year. On the evening of January 5 an informal dinner will be given at the University Club, to which the engineers of Washington will be among those invited.

F. A. E. S. EMPLOYMENT SERVICE EXPANDING

New York Committee Stimulates Demand for Engineers

In an endeavor to improve the present conditions of unemployment particularly as affecting engineers, a voluntary committee was formed at New York heaquarters in November of unemployed members of the national societies residing in the vicinity of the city. The objects in view are to uncover positions now open, to locate future prospective openings, to spread the gospel of what engineers can do, and to acquaint all employers with the facilities, provided free of charge to both parties by the Federated American Engineering Societies, for securing the services of engineers specially qualified to handle their problems.

Profiting by the experience of a similar previous committee, which functioned during the summer, the present committee is working through the medium of personal calls; it having been found that letter writing and circularizing are much less effective.

The original committee, confining its activities to firms employing members of the Federated American Engineering Societies, made 2300 calls and secured 1800 interviews. It also secured write-ups and editorials in over 50 technical and daily papers, thus arousing considerable interest and doing splendid work in advancing the cause of the engineering profession. Although the actual number of opportunities learned of was not great, it should be borne in mind that this work was carried on during the period of greatest depression and the benefit of the efforts will become evident to the Bureau as conditions improve.

The present committee is branching out into a still broader field not only by making repeat calls on the most likely of the original prospects, but also by calling on firms not hitherto interviewed, and endeavoring to create a demand for engineering services in lines not ordinarily using engineers; such as banks, insurance concerns, department stores, accountants, etc.

The work presents such splendid possibilities, and is of such importance and value, that it should not be confined merely to the New York district but should be carried on with equal initiative throughout the entire country, and members of various sections have expressed their intention of inaugurating similar committees, in their local districts. The Employment Service is most eager to encourage and cooperate in this work.

Full information as to details may be obtained by writing to Mr. W. V. Brown, Manager, Employment Service, Federated American Engineering Societies, 29 West 39th Street, New York, N. Y.

Nomination and Election of Institute Officers for 1922-1923

As provided in Section 19 of the Institute By-Laws, candidates may now be proposed for nomination for the offices to be filled at the next annual election in May, 1922, by the petition or by the separate endorsement in writing, of not less than twenty-five members. The petitions or separate endorsements must be in the hands of the Secretary not later than January 25, 1922. For the convenience of members, a form of petition has been prepared by the Secretary, and copies of it may be obtained upon application to Institute headquarters. Endorsements may, however, be made by letter if the form is not available. A member is not limited in the number of candidates he may endorse in this manner.

The officers to be elected are: A President and a Treasurer for the term of one year each, five Vice-Presidents for the term of two years each (one from each of the odd numbered geographical districts), and three Managers for the term of four years each.

The five odd numbered districts from which Vice-Presidents are to be chosen at the May 1922 election are as follows:

1. North Eastern: Connecticut, Maine, Massachusetts, New Hampshire, New York (exclusive of N. Y. Section territory), Rhode Island, Vermont.

3. New York City: Territory of the New York Section, Canal Zone, Porto Rico, all foreign countries (Canada excepted).

5. Great Lakes: Illinois, Indiana, Michigan, Wisconsin.

7. South West: Arkansas, Kansas, Missouri, New Mexico, Oklahoma, Texas.

9. North West: Idaho, Montana, Oregon, Utah, Washington, Alaska.

According to the revised Constitution, while one Vice-President must be elected from each of the five odd numbered districts, this does not debar members in one district, if they so wish, from nominating and voting for a candidate in another district. When the votes are counted the candidate for Vice-President having the largest vote in each district will be elected to that particular office for that district, irrespective of the fact that he may have polled a smaller number of votes than a candidate standing second in another district.

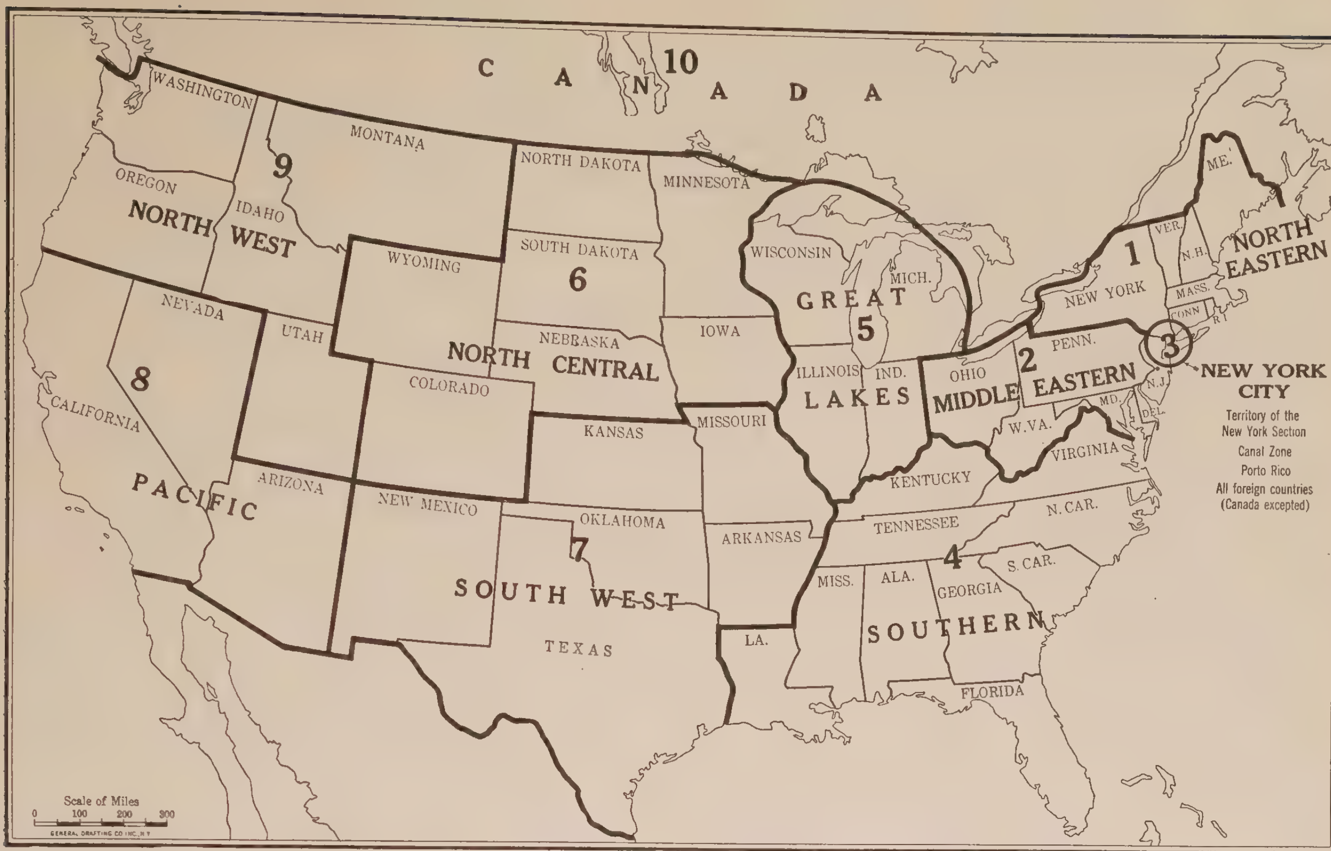
For the information of members the full text of revised sections of the Constitution and By-Laws applying to Officers, nominations, elections, etc., are printed below:

CONSTITUTION

Sec. 23. The officers of the Institute shall be a President, one Vice-President from each geographical district as defined in the By-Laws, twelve Managers, a Secretary and a Treasurer.

Sec. 24. The President, the Secretary and the Treasurer shall hold office for one year, the Vice-Presidents for two years and the Managers for four years. The President and Managers shall not be eligible for immediate re-election to the same office. No Vice-President or Manager who has served continuously in one or more offices, and whose combined terms shall have aggregated six years or more shall be eligible for immediate election to the office of Manager or Vice-President. At each Annual Meeting the President, the requisite number of Vice-Presidents to fill vacancies caused by expiration of terms, three Managers and the Treasurer shall be elected by the membership, and their terms of office shall commence on the first of August next succeeding their election. . . . .

Sec. 24A. At the election of Vice-Presidents held in 1921 there shall be elected one Vice-President from each geographical district, those from the odd-numbered districts to serve for one year each, and those from the even-numbered districts two years each. All Vice-Presidents elected thereafter shall serve for two years each. In the event of a change in the geographical districts, the Vice-Presidents then in office shall complete their terms. In case of revisions of the geographical districts, the Board of Directors shall have the power to elect a Vice-President from each district not represented, to serve until the next election covering these districts.



Geographical districts into which the membership of A. I. E. E. has been divided for the purpose of electing Vice-Presidents.

BY-LAWS

Sec. 19. In addition to the names of the incumbents of office the Secretary shall publish on the "form showing offices to be filled at the ensuing annual election in May provided for in Article VI, of the Constitution, the names, as candidates for nomination, of such members of the Institute as have been proposed for nomination for a particular office by the petition or by the separate endorsement of not less than twenty-five members, received by the Secretary of the Institute in writing by January twenty-fifth of each year; provided, however, that any candidate proposed for nomination by petition may withdraw his name by written communication to the Secretary, and any name so withdrawn prior to the printing of the form shall not be published.

The names of such candidates for nomination shall be grouped alphabetically under the name of the office for which each is proposed, and this by-law shall be reprinted prominently in the December and January issue of each year's Journal and shall be reproduced on the form above referred to.

Sec. 21. There shall be ten geographical districts grouped as follows: (For the balance of this Section describing districts see By-laws and map.)

Sec. 21A. Should the territory of any Institute Section lie in more than one geographical district as defined above, then the entire territory of said Section shall be considered as belonging to the geographical district in which the headquarters of the Section are located.

Edison Pioneers

REVISED CONSTITUTION PROVIDES FOR ADDITIONAL MEMBERSHIP

At a meeting of the Edison Pioneers held in New York on November 3, 1921, a revision of the society's Constitution and By-Laws was read and approved. The revised Constitution provides for a class of membership to be known as "Descendant Members," to consist of the sons or daughters of actual members, who may be elected to membership during the life of the parent member, or by the Executive Committee should the parent member be deceased, it being resolved that but one such son or daughter should be eligible for membership at a time.

This will form a practically endless chain, and presents the opportunity for membership to many, hitherto debarred, whose parent now deceased would have been eligible to membership in the Society upon its formation, or since. In this way the society plans to perpetuate its organization.

Through the courtesy of the Association of Edison Illuminating Companies, the Edison Pioneers share with them rooms in the Engineering Societies Building, 29 West 39th Street, New York City, where it is the intention to gather together, if possible, models of early apparatus and such other articles of historical and educational value as may be obtainable, for the conception and ultimate practical utilization of which the scientific and industrial world owes so much to the genius and achievements of Thomas Alva Edison.

The officers of the Edison Pioneers are: Frederick A. Scheffler, president, Charles E. Estabrook, treasurer, Wm. H. Meadowcroft, historian, Frank A. Wardlaw, secretary pro tem.

The Secretary's office is temporarily located at Room 2077, 50 Church Street, New York City.

National Research Council

FREE INFORMATION SERVICE ESTABLISHED

The Research Information Service of the National Research Council is prepared to supply to those interested, information about scientific instruments, apparatus and supplies, laboratory construction and equipment.

The following are samples of requests answered recently:

Where may we purchase inexpensive photomicrographic apparatus?
Where may a human skull be purchased?
Who manufactures a good grade of selenium cells?
Advise where lantern slides on European Geography may be obtained.
Where may the Lummer-Brodhun cube be obtained?
What concern makes gages recording in fractions of an ounce?
Where may apparatus and accessories for the study of sensitiveness of photographic plates be secured?

Requests should be addressed to National Research Council, Information Service, Washington, D. C.

Licensing of Engineers in New York State

The new law in New York State that electrical, mining, mechanical, chemical, or civil engineers practising in the state must be licensed, has just begun to function. A board of five engineering examiners, representing each of these branches, passes upon all applications. The present board is composed as follows: President, Mr. Albert H. Hooker, chemical engineering, of Niagara Falls; vice-president, Major Percy E. Barbour, mining engineering, of New York City; secretary, Mr. Henry G. Reist, electrical engineering, of Schenectady; Mr. Virgil M. Palmer, mechanical engineering, of Rochester; and Col. Walter G. Eliot, civil engineering, of New York.

At a recent session of the board at Albany the first list of 241 applicants was considered and 171 passed. Among them was a large number of the most prominent engineers of the state and country.

Registration of Engineers in Pennsylvania

By June 1, 1922, all professional engineers or land surveyors practising in the state of Pennsylvania must be registered, or exempted under certain provisions, accord ng to the Act of the General Assembly, No. 422, approved May 25, 1921. All applicat ons for a Certificate of Registration should be made as early as possible. The fees required by the Act are as follows: Professional engineer, $20; land surveyor, $20; professional engineer and land surveyor, $30.

Application blanks may be obtained from the "State Board for Registration of Professional Engineers and of Land Surveyors," Harrisburg, Pa.

American Engineering Standards Committee

WAR DEPARTMENT USING A. E. S. C. STANDARDS

The Secretary of War has directed that "The Supply Branches of the Army utilize in connection with their specifications the standards that have been or may be adopted by the American Engineering Standards Committee."

There are seven supply branches of the Army: The Quartermaster Corps, which purchases all general supplies of a commercial character; Ordnance Department; Medical Department; Corps of Engineers; Signal Corps; Chemical Warfare Service; and Air Service.

The standardization of war supplies is of great importance, and the adoption of the A. E. S. C. Standards by the War Department is a policy to support a national program of engineering and industrial standardization.

Personnel Research Federation

FIRST ANNUAL MEETING

The first annual meeting of the Personnel Research Federation was held in Washington, D. C., November 21, 1921. The all-day meeting was enthusiastic and helpful, with addresses made by Chairman Yerkes, Vice-Chairman Gompers (read by Mr. Matthew Woll), and Secretary Flinn; and papers read by C. S. Yoakum, Director, Bureau of Personnel Research, Carnegie Institute of Technology, Pittsburgh; Joseph W. Hayes, of The Scott Company; L. L. Thurstone, of the Carnegie Institute of Technology; and Miss Anna Bezanson, of the Wharton School of Commerce, University of Pennsylvania.

The membership of the Personnel Research Federation was increased from 8 to 24. A proposal for a journal, to be edited under the auspices of the Federation, was favorably received, and referred to a committee for investigation of its feasibility at the present stage in the development of the Federation.

The following officers were elected: Robert M. Yerkes, National Research Council, chairman; Samuel Gompers, American Federation of Labor, vice-chairman; Alfred D. Flinn, Engineering Foundation, Secretary; Robert W. Bruere, Bureau of Industrial Research, treasurer; and Leonard Outhwaite, Columbia University, director.

Report Issued by National Industrial Conference Board

METRIC VS. ENGLISH WEIGHTS AND MEASURES

Report No. 42, issued by the National Industrial Conference Board, is a very complete review of the present status of the metric and English systems of weights and measures. It is intended as an unbiased presentation of the relative merits of the two systems, or perhaps, more accurately, an impartial collection of evidence bearing upon the desirability of compulsory adoption of the metric system in the United States. The report was prepared under the guidance of an advisory board, consisting of Messrs. E. M. Herr, Chairman, president, Westinghouse Electric & Manufacturing Company; Fred J. Miller, past president, American Society of Mechanical Engineers; Henry D. Sharpe, of the Browne & Sharpe Manufacturing Company; Henry R. Towne, of Yale & Towne Manufacturing Company; and Frank O. Wells, formerly president of the Greenfield Tap & Die Company. These names are a guarantee of the accuracy and thoroughness with which the subject has been treated.

The report is divided into three sections: Section one presents some brief notes as to the origin and development of the systems and a concise but sufficient statement of the measuring systems predominating in the 77 countries of the world, one entire chapter being given to discussion of weights and measures in the United States. Three very interesting diagrams are given showing that the twelve countries where the English system predominates have 22 per cent of the population of the world and furnish 48 per cent of the exports, while 37 metric countries with 25 per cent of the population furnish 37.5 per cent of the exports. Exports of the United States are divided in the proportion of 42 per cent to English countries and 37 per cent to European metric countries.

Section two discusses the applications of the two systems to fields of science, engineering, manufacturing and trade in this and other countries. Of the thirty-eight million people in the United States employed in gainful occupations 35.6 per cent are employed in agriculture and mining; 28 per cent in manufacturing and construction; 16.4 per cent in transportation and trade; and 4. 4 per cent in professional occupations, including science and engineering, which two employ something less than 140,000 or about 4/10 of 1 per cent of those gainfully employed. Each of these groups is subdivided and analyzed in detail as to the influence of weights and measures in each subdivision. This section is of especial value as it contains a great deal of information not otherwise available except at the expense of considerable time and trouble.

Section three is a presentation of the various arguments advanced by the proponents and opponents of the metric system. Excellently arranged, this summing up brings together the opposing views on the different aspects of the problem, but of course contains very little new material. It is rather a careful compilation of everything which has been said on both sides of the subject.

The report concludes with a few interesting statistical tables and a quite complete bibliography.

Taken as a whole the report is of the greatest value, particularly at the present time. It contains all the information necessary for a complete understanding of the subject. It is well arranged, clearly printed in good paper, abounds in references to original articles from which quotations are taken, and is highly creditable to those who have taken part in its preparation. It attempts to hold the scales evenly and yet it creates a distinctly anti-metric atmosphere.

The report may be obtained at $2.50 per copy ($3.00 cloth) by addressing National Industrial Conference Board, 10 East 39th Street, New York, N. Y.

PERSONAL MENTION

F. M. DOOLITTLE has resigned his instructorship at Yale in order to devote his time to his electrical manufacturing interests in New Haven.

C. A. YARRINGTON, formerly with MacGovern and Company, Inc., New York City, has become sales engineer with the Tiffany Electric Company, of New York.

E. C. BURKE has left the Chicago office of the General Electric Company to become connected with the Central Illinois Public Service Company, at Mattoon, Ill.

R. H. RICHARDS, for the past four years with the Braden Copper Company, Rancaigua, Chile, is now with the Compania Chilena de Electricidad, Ltda., of Santiago, Chile.

R. H. TERRY has left his work as laboratory instructor in the University of Wisconsin to enter the employ of the Pacific Coast Electrical and Supply Company, Los Angeles, Cal.

VICTOR L. RONCI, of the Western Electric Company, N. Y. has had to leave work indefinitely on account of illness. His present address is 19 Broadway, Saranac Lake, N. Y.

FRANCIS E. COXE has resigned his position with the Standard Underground Cable Company, Perth Amboy, N. J., and is engaged in private research work at Bennetsville, S. C.

EDWARD L. HIRT is now located with the Canadian Engineering Agency, New York City. He was formerly a welding engineer with the Bethlehem Shipbuilding Corporation, Ltd.

RAYMOND E. SPARKS, until recently with the Citizens Telephone Company, Grand Rapids, Mich., has entered the employ of the Southern California Telephone Company, Los Angeles.

F. R. WINDERS has joined the engineering staff of the National Electric Light Association in New York City. Mr. Winders was until recently with the Railroad Commission of Wisconsin.

GEO. J. LECHNER has recently become sales engineer with The Edward-Johns Company, Cleveland. He was previously connected with the L. K. Comstock Company, Cleveland office, in a like capacity.

KEENE RICHARDS, formerly division superintendent with the Public Service Company of Northern Illinois, Chicago, is now located in Detroit, Mich., as industrial engineer with the Grennan Cake Corporation.

GEO. L. HEDGES, until recently engineer with the Stewart Wire Wheel Company, Frankfort, Ind., is at present engaged in some special design and development work with the P. A. Geier Company, Cleveland, Ohio.

A. C. PERRY, formerly designing draftsman with the American Rolling Mill Company, Middletown, Ohio, has become assistant industrial engineer with the Jones and Laughlin Steel Company South Side Works, Pittsburgh, Pa.

JAMES LYNAH, formerly works manager with the E. I. duPont de Nemours and Company, is vice-president of Barnard-Lynah, Inc., selling agents for cotton mills making coarse cotton fabrics, tire fabrics and yarns, with offices in New York City.

A. D. KEENE, until recently electric furnace engineer of the General Electric Company, Schenectady works, is now located in Pittsburgh with the Pittsburgh Electric Furnace Corporation as engineer on electric furnace designs and applications in the steel and metal industries.

R. B. TURNER has organized with W. A. Johnson the firm of Johnson-Turner, electric repair and engineering company, Walkerville, Ont. Mr. Turner is manager and electrical engineer of the company. He was previously with the Western Electric and Manufacturing Company, E. Pittsburgh.

ALLAN D. COLVIN, of Hartford, Conn., has been appointed general manager of the Hartford Electric Light Company. He has been with this company since 1911, when he became assistant to the general manager, and during 1919 and 1920 was acting general manager in the absence of general manager E. F. Lawton. Mr. Lawton lately resigned his office on account of ill health.

HARRISON G. THOMPSON is now connected with the American Radio and Research Corporation, Medford Hillside, Mass., as general sales manager. Mr. Thompson has been president of the Transportation Engineering Corporation, New York City, since 1919, and was previously vice-president and general sales manager of the Edison Storage Battery Company, West Orange, N. J.

R. A. ROSS, who for three years has been a member of a commission in Montreal appointed to administer the city affairs, recently resumed his engineering work in the firm of R. A. Ross and Company, Montreal. This consulting engineering firm was founded in 1896 under the title of R. A. Ross, later changed to Ross and Holgate, and then to R. A. Ross and Company. Its engineering activities have been conducted not only in Canada, but also in the United States, and various foreign countries. Mr. Ross is a Fellow of the Institute.

E. W. RICE, JR., president of the General Electric Company, was recently elected to honorary membership in the Tau Beta Pi society, a national honorary engineering society holding an important place in the engineering colleges of the country. The initiation was conducted by the Schenectady, N. Y., Alumni Association of Tau Beta Pi, on December 17, and the ceremony was attended by sixty-five members of the local association and by several representatives from Columbia University. Mr. Rice is a Fellow of the A. I. E. E., and prominent in its activities, having served as president 1917-1918.

WILLIAM A. DURGIN, secretary of the Budget and Exp nse Committee and secretary of the Advisory Committee of the Commonwealth Edison Company, Chicago, became associated on December 1, with the Department of Commerce, Washington, D. C., under Secretary Hoover. He will head a new division of a bureau in Washington with the purpose of accomplishing the government's new program of eliminating waste in industry by simplification. Mr. Durgin has been with the Chicago Edison Company and its successor the Commonwealth Edison Company since 1904, and expects to return there when his work with the government is finished.

LOUIS LEHURAUX sailed for India in December to take up work as technical assistant to the general manager of the Tata Hydroelectric Power Supply Company, Bombay. Mr. Lehuraux has been connected with various departments of the General Electric Company for over sixteen years. From 1913 to 1915 he was with the Tata Company in Bombay as chief erecting engineer for the General Electric Company. During the war he served for 22 months in the French army, and since that time has been with the International General Electric Company at Schenectady, N. Y. Mr. Lehuraux was born in India and received his early education there, later attending the Central Technical College of London.

DEXTER S. KIMBALL, dean of the College of Engineering, Cornell University, has been elected president of the American Society of Mechanical Engineers for the year 1922. Dean Kimball is vice-president of the Federated American Engineering Societies, and has been active in various phases of engineering work. Other officers elected by the American Society of Mechani-

cal Engineers for the coming year include Edward A. Deeds, vice-president, and Walter S. Finlay, Jr., a manager. Colonel Deeds has been prominent in industrial engineering lines, and belongs to a number of engineering societies. Mr. Finlay, connected for a number of years with the Interborough Rapid Transit Company of New York City, and more recently vice-president of the American Water Works and Electric Company, is a member of the A. I. E. E.

Obituary

Robert McKay, K. C., a brief notice of whose death on November 6 last was printed in the December Journal, was an outstanding member of the legal profession in Toronto, exceptionally well qualified for handling electrical litigation. With an analytic mind and large intellectual faculties, he had a fundamental scientific knowledge which rendered it easy to grasp engineering questions involved in complicated cases. During several years past he was engaged in litigation involving some very intricate technical and legal questions in controversy between large power interests at Niagara, some of the questions being the outgrowth of emergency conditions arising during the war. In this connection several members of the Institute have been called as experts. Mr. McKay belonged to the Toronto Section of the Institute, and probably few members of the Institute have been more interested and faithful readers of the Transactions or have taken more active pride in their affiliation with the Institute. His sudden death at the age of 53, resulting from blood poisoning following an operation, was a shock to his many friends.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is administered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 6 p. m.

A LIST OF BOOKS ON THE ELECTRON

Compiled by Harrison W. Craver

Director Engineering Societies Library

This list owes its origin to a suggestion from Professor V. Karapetoff, of Cornell University, that a brief list of references would be useful to students of electrophysics.

It is intended as a guide to some of the more important books on the electron; books from which a correct understanding of present knowledge about the nature and properties of electrons may be obtained. No attention has been paid to the numerous important articles that have appeared in periodicals.

Professor Karapetoff and Professor E. Merritt, also of Cornell University, have assisted materially by evaluating the longer list from which selection has been made, and the final list has their approval. Whatever merit it may have is due to their intelligent, helpful criticism.

Abraham, M. "Theorie der Electrizitat." Ed. 3. 1914. Leipzig, Teubner. 10 M.

Allen, H. S. "Photo-Electricity." 1914. New York, Longmans. $2.10.

Campbell, N. R. "Modern Electrical Theory." Ed. 2. 1914. New York. Putnam. $2.75.

Comstock, D. F. & Troland, L. T. "Nature of Matter and Electricity." 1917. New York, Van Nostrand Co. $2.00.

Cox, John. "Beyond the Atom." 1913. New York, Putnam. $.40.

Crowther, J. O. "Ions, Electrons and Ionizing Radiations." 1920. New York, Longmans. $4.00.

Cunningham, E. "Relativity, the Electron Theory and Gravitation." Ed. 2. 1921. New York, Longmans. $3.50.

Curtis, H. A. "Electron Theory." 1912. Denver, Colorado Scientific Society.

Fleming, J. A. "Thermionic Valve and its Developments in Radio-Telegraphy and Telephony." 1919. London, Wireless Press. 15s.

Hughes, A. L. "Photo-Electricity." 1914. Cambridge University Press.

Lamor, Joseph. "Aether and Matter." 1920. London.

Lodge, O. J. "Electrons." 1907. New York, MacMillan. $2.00.

Lorentz, H. A. "Theory of Electrons." 1909. New York, G. E. Stechert. $2.50.

Millikan, R. A. "The Electron." 1917. Chicago, University of Chicago Press. $1.50.

Perrin, J. B. "Atoms." 1917. New York, Van Nostrand. $2.50.

Ramsay, William. "Elements and Electrons." 1912. New York, Harper. $.75.

Richardson, O. W. "Electron Theory of Matter." Ed. 2. 1916. New York, Putnam. $4.50.

—— "Emission of Electricity from Hot Bodies." 1916. New York, Longmans. $2.75.

Rutherford, Ernest. "Constitution of Matter and the Evolution of the Elements." 1916. Washington, Smithsonian Institution. Free.

—— "Radioactive Substances." 1913. New York, Putnam. $4.50.

Soddy, Frederick. "Interpretation of Radium." Ed. 4. 1920. New York, Putnam. $3.75.

—— "Matter and Energy." 1912. New York, Holt. $.75.

Thomson, J. J. "Conduction of Electricity Through Gases." Ed. 2. 1906. New York, Putnam. $4.00.

—— "Corpuscular Theory of Matter." 1907. New York, Scribner. $2.00.

Townsend, J. S. "Electricity in Gases." 1915. New York, Oxford University Press. $4.75.

BOOK NOTICES (NOV. 1—30, 1921)

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statements made; these are taken from the preface or the text of the book.

All the books listed may be consulted in the Engineering Soceities Library.

CENTRAL STATION RATES IN THEORY AND PRACTISE.

By H. E. Eisenmenger. Chicago, Frederick J. Drake & Co., 1921. 382 pp., illus., 7 x 5 in., fabrikoid.

A text-book for students of electric rates, intended to meet the needs of both beginners and experts. Discusses the cost of electric service, its price, systems of charging, rate analysis, the accuracy of rates and public regulation of public utilities. Appeared serially in the *Electrical Review*.

DIAGNOSING OF TROUBLES IN ELECTRICAL MACHINES.

By Miles Walker. Lond. and N. Y., Longmans Green and Co., 1921. 450 pp., diagrs., 10 x 7 in., cloth $10.50.

During the last thirty years the author of this book has had a large number of troubles in connection with electrical machinery brought to his notice, many of which were difficult to diagnose and correct. He here attempts to record his experience in logical order, to assist others when dealing with similar troubles. The book discusses troubles due to defective insulation, overheating, low efficiency, and those peculiar to alternating and dierect-current generators and motors, sycnhronous converters, motor-generators and induction motors. It is especially concerned with troubles in the field, not with factory tests.

ELEKTRISCHE FORDERMASCHINEN.

By W. Philippi. Liepzig, S. Hirzel, 1921. 304 pp., illus., 9 x 6 in., paper.

The use of electric hoisting machinery in mining is covered from several viewpoints, mechanical, electrical and economic with special stress upon the last aspect of the question. The question, whether electric hoisting shall be adopted for a given mine, is the one to which most attention is given.

RAILWAY SIGNALING.

By Everett Edgar King. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 371 pp., illus., diagrs., 9 x 6 in., cloth. $4.00.

The purpose of this book is to collect what is already in common practise in railway signaling and to present it in text-book form, suitable for use by those beginning the study of this subject. The volume discusses signal indications, interlocking, block signaling, signal mechanism and highway crossing signals.

ELECTRONS AND ETHER WAVES, being the Twenty-Third Robert Boyle Lecture.

By Sir William Bragg. Lond. and N. Y., Oxford University Press, 1921. 14 pp., 9 x 6 in., paper. $.45.

This address is concerned with one of the outstanding problems in physics, the connection between ether waves and electrons and the relation between the wave length of the ether radiations and the velocity of the ejected electrons. The lecture gives a non-mathematical account of our present information on the matter.

PHYSICAL PROPERTIES OF COLLOIDAL SOLUTIONS.

By E. F. Burton. Second edition. Lond. and N. Y., Longmans Green and Co., 1921. (Monographs in physics.) 221 pp., illus., 9 x 6 in., cloth. $4.25.

This outline of the study of colloidal solutions has to do particularly with their relation to the development of physics. For this reason an extended treatment is given of the development of the ultra-microscope and the confirmation of the kinetic theory of matter by the Brownian movement. In this new edition the book has been throughly revised and partly rewritten.

ELEMENTS D'ANALYSE MATHEMATIQUE.

By Paul Appell. 4th edition. Paris, Gauthier-Villars, et Cie, 1921. 715 pp., 10 x 7 in., paper. 65 fr.

This text-book of the elements of mathematical analysis pays particular attention to the use of analysis in geometry, physics and mechanics, and is intended for engineers and physicists. Numerous examples of the applications of analysis are included, and all theories are illustrated by application to particular cases.

This edition has been revised throughout and extended considerably.

EARLY SCIENCE IN OXFORD. Part 1. Chemistry.

By R. T. Gunther. Lond., Hazell, Watson and Viney, Ltd., 1920. 91 pp., illus., plates 8 x 6 in., paper. $3.50. (Gift of Oxford University Press, American Branch.)

This account of early study of chemistry at Oxford traces the story from its beginnings, with Roger Bacon in 1214, down to the early nineteenth century. It is the first attempt to bring together such scattered information as is relevant to a fuller history of the progress of science, and will be followed by parts treating of other branches. An interesting account is given of early Oxford chemists, of laboratories and their apparatus.

MACHINE DRAWING.

By Carl L. Svensen. N. Y., D. Van Nostrand Co., 1921. 214 pp., illus., 9 x 6 in., cloth. $2.25.

This text-book is intended for students who have had previous instruction in mechanical drawing and is intended to develop an understanding of the relation of machine drawing to engineering. It includes a complete treatment of working drawings, drafting room practise, a chapter on the principles and practise of dimensioning, a study of the common machine details, jigs and fixtures, and a large collection of problems.

GRAPHICAL METHODS.

By William C. Marshall. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 253 pp., charts, 9 x 6 in., cloth. $3.00.

A general treatise on the construction and use of graphical charts. Includes charts intended to appeal to the general public, those of interest to executives and those intended to facilitate engineering and scientific calculations. Gives many examples of the application of charts to a great variety of purposes and contains an extensive bibliography of published charts.

SPECIAL LIBRARIES DIRECTORY

Edited by Dorsey W. Hyde, Jr. Wash. Special Libraries Association, 1921. 123 pp., 9 x 6 in., paper. $2.00.

This directory is a comprehensive survey of the specialized collections of literature upon various subjects in the United States. Over 1300 libraries belonging to universities, societies, business houses and other agencies are listed, with their location, rules for use and brief accounts of their resources. The list is arranged by subject and also geographically. Many of these libraries are concerned with engineering and allied subjects. The list will prove valuable to research students, in indicating sources of information.

INVENTION THE MASTER-KEY TO PROGRESS.

By Bradley A. Fiske. N. Y., E. P. Dutton & Co., 1921. 356 pp., illus., 8 x 6 in., cloth. $4.00.

The thesis of this author is that invention, acting through literature, science, art, war and the other activities of men, has initiated all creative human progress; and his book is an interesting account of what inventors have accomplished through the ages, and a forecast of what may be done in the future, if the art of invention is properly fostered.

MECHANICAL HANDLING OF GOODS.

By C. H. Woodfield. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. (Technical primers.) 116 pp., illus., 6 x 4 in., cloth. $.85.

The object of this book is to set forth sufficient information upon the handling of goods and material to enable the uninitiated to understand the methods and equipment employed and appreciate the economic possibilities of dealing with goods by mechanical methods.

TIDAL POWER

By A. M. A. Struben. Lond. and N. Y., Sir Isaac Pitman & Sons, Ltd., 1921. 115 pp., diagrs., 6 x 4 in., boards. $.85.

This little book is intended to stimulate interest in a field that is likely to attract attention in the near future. It indicates some of the possibilities, the difficulties that are found and the systems that have been proposed.

POWER'S PRACTICAL REFRIGERATION.

Compiled by the Editorial Staff of *Power*. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 283 pp., illus., tables, 8 x 6 in., fabrikoid. $2.00.

A volume dealing with the practise of refrigeration, but also including the laws governing its production. Chiefly made up of articles that have appeared in *Power* and have proved of particular value to those operating refrigerating plants.

LES COMBUSTIBLES LIQUIDES ET LEURS APPLICATIONS.

By the Syndicat d'Applications Industrielles des Combustibles Liquides. Paris, Gauthier-Villars et Cie, 1921. 621 pp., illus., 6 x 4 in., cloth.

This handbook, published by an association of French companies interested in the production and use of liquid fuel, has been prepared as a practical guide to users and dealers. It includes the regulations governing the importation and use of liquid fuels, insurance laws, brief descriptions of the chief oil-producing countries, the principal fuel oils and lubricants and methods for testing them. Descriptions of the leading French types of internal combustion engines, furnaces and boilers are given, and directions for storing and shipping oil. The final section consists of conversion tables and coefficients.

PORT OF NEW YORK ANNUAL.

Compiled and edited by Alexander R. Smith. N. Y., Smith's Port Publishing Co., Inc., 1920. 526 pp., illus., 11 x 8 in., cloth. $5.00.

The information here presented will be of interest to merchants and shippers generally, for it covers the port of New York in a large way, and discusses its problems from many angles. The present and proposed facilities in the various boroughs of New York and in Newark and Jersey City are described with considerable detail. Information is also given upon railroad and canal connections to the port, upon the Hudson River vehicular tunnel, and similar facilities. There is also a large amount of statistical information on port matters, both maritime and economic.

ANNALS OF THE AMERICAN ACADEMY OF POLITICAL AND SOCIAL SCIENCE. May 1920. Vol. 89, No. 178. 289 pp., 9 x 6 in., paper. $1.25.

This volume of essays discusses the economic significance of present day prices, price factors in typical commodities, wages, profits and excess profits taxes, production, cooperation, international finance and trade in their relation to prices, inflation and prices, and the world's monetary problems. The papers included are by well-known economists, business men and engineers.

EMPLOYMENT MANAGEMENT, WAGE SYSTEMS AND RATE SETTING.

First edition. N. Y., The Industrial Press, 1921. 103 pp., 9 x 6 in., paper. $1.00.

This concise description of systematic methods of employing and placing men, and of wage payment systems, is based on articles that have appeared in *Machinery*, describing the practise in the Westinghouse Electric and Manufacturing Company, R. K. LeBlond Machine Tool Company, Norton Company and other manufacturing plants.

PROFIT SHARING BY AMERICAN EMPLOYERS.

A report of the Profit Sharing Department of the National Civic Federation. N. Y., E. P. Dutton & Co., 1921. 416 pp., 8 x 5 in., cloth. $8.00.

The first edition of this book, published in 1916 by The National Civic Federation, was based on analyses of more than two hundred plans for profit-sharing in use in this country. It was intended to present testimony from managers of manufacturing establishments, concerning the success and failure of such plans.

This edition is practically a new book, as much of the former material has been omitted and numerous additions have been made, enlarging the book and bringing it up to 1919.

WASTE IN INDUSTRY.

By the Committee on Elimination of Waste in Industry of the Federated American Engineering Societies. First edition. N. Y. and Lond., McGraw-Hill Book Co., Inc., 1921. 409 pp., charts, tables 9 x 6 in., cloth. $4.00.

This committee of seventeen engineers was appointed in January 1921, by Herbert Hoover, first president of the Federated American Engineering Societies. It was instructed to gather quickly concrete information that might stimulate action on the elimination of waste and lay the foundation for further study.

The present report is an analysis of waste in six typical branches of industry (building industry, men's clothing manufacturing, shoe manufacturing, printing, metal trades, textile manufacturing), based on five months of intensive study, carefully planned and rapidly executed. It discloses losses and waste due to the restraint and dissipation of creative power of those who work in industry, and presents for the first time a collective endorsement of a general analysis of the sources and causes of waste and recommendations for its elimination.

Past Section and Branch Meetings

SECTION MEETINGS

Akron.—November 22, 1921, Rooms of Engineering Society of Akron. Paper: "Modern Practise in Transformer Design." Author: Mr. J. G. Corrin, of the Pittsburgh Transformer Company. The paper was illustrated with lantern slides. Attendance 57.

Baltimore.— November 18, 1921, Engineers Club of Baltimore. A discussion on the Superpower Survey Report was presented by Mr. W. S. Murray, who served as Director of the Superpower Survey. Mr. Murray's discussion dealt with the broad aspects of the subject rather than with the engineering details. He pointed out that the most immediate need for additional power development lies in the region around New York City and the recommendation is embodied in the Superpower Survey Report that in the near future a large steam generating station be built near Pittston, Pa., on the Susquehanna River, and that power be transmitted from this steam generating station to the vicinity of Newark, N. J., by means of a 220,000-volt transmission line. It was pointed out that the need for additional power development and the tying-in with other districts was very much less urgent for the southern part of the zone than for the northern and central parts and that it seems unlikely that Baltimore and Washington will be tied in with the rest of the system for some years. Attendance 65.

Boston.—November 16, 1921. Joint meeting of Boston Sections of A. I. E. E. and A. S. M. E., Jefferson Physical Laboratory, Harvard University. Subject: "Electric Waves and Their Application to Radio Telegraphy and Telephony." Speaker: Professor E. Leon Chaffee. Professor Chaffee discussed wave motion in general and then gave experimental demonstrations of some of the properties of waves of light, heat and electricity. Attendance 400.

Chicago.—November 28, 1921, Joint meeting with the Western Society of Engineers. Subject: "The Elements of the Elements" (illustrated). Speaker: Dr. W. P. Davey, of the Research Department, General Electric Company, Schenectady. The lecture covered an outline of the electron theory, the X-ray, spectroscopic study of crystal structure, the space lattice theory of matter, and biological investigations relating to the effect of X-rays in the propagation of insects. Attendance 200.

Cincinnati.—December 8, 1921, Assembly Hall of Union Gas & Electric Company. Subject: "Pyrometers—What They Are and Why" (illustrated by lantern slides). Speaker: Mr. Robert W. Mayer, of the Brown Instrument Company, Philadelphia, Pa. Attendance 30.

Cleveland.—November 15, 1921. Joint meeting with Cleveland Radio Association. Subject: "Radio Telephony." Speaker: Mr. Ralph Bown, Department of Development and Research, of the American Telephone and Telegraph Co., New York. The speaker explained briefly the underlying principles of radio telephony and outlined its possibilities and limitations. Attendance 147.

Connecticut.—November 18, 1921, Bridgeport, Conn. In the afternoon some thirty-five members and guests visited the Bridgeport Works of the General Electric Company and

observed the manufacture of wiring supplies under model conditions in the newly acquired plant. Then followed a dinner at the Stratfield Hotel, Bridgeport. The speaker of the evening was Mr. W. Stewart Clark, Works Manager, Bridgeport General Electric Company, whose topic was "Manufacture of Electrical Apparatus." Motion pictures were shown of the General Electric Company plant; the structure of the atom; and the use of electricity in the lumber industry. Attendance 80.

Denver.—November 19, 1921, Adams Hotel. After dinner, the Chairman introduced Mr. W. H. Bullock, of the Westinghouse Company, who presided at the receiving apparatus of radio equipment by means of which the audience was entertained for a half hour by a concert sent by Mr. W. L. Winner from his station at the Fitzsimmons General Hospital at Aurora, about ten miles distant. Mr. J. F. Greenawalt, Publicity Manager of the Mountain States Telephone & Telegraph Company, was then ntroduced and made a short address on "Public Relations of the Public Utilities." He announced the following program, which was rendered in an excellent and very pleasing manner: several musical selections and a demonstration of the passing of local telephone calls of different types, and the avoidance of some of the difficulties likely to be experienced by the subscriber and operator. This program was rendered by eighteen employees of the Mountain States Telephone & Telegraph Company, mostly women. Attendance 110.

Detroit-Ann Arbor.—November 11, 1921, Detroit Edison Company's new service building. Subject: "Industrial Lighting." Speaker: Mr. H. T. Spaulding of the National Lamp Works of the General Electric Company, at Nela Park, Cleveland. The speaker brought with him a lighting cabinet and a lot of apparatus to demonstrate the different ways and means of obtaining proper light. Attendance 50.

November 18, 1921, Detroit Institute of Arts. Joint meeting with Associated Technical Societies of Detroit. Subject: "Modern Concrete Road Construction." Speaker: Mr. William Ord, of the Lakewood Engineering Company of Cleveland. Mr. Ord's moving pictures were very well taken and showed in a convincing manner the modern method of road building. Attendance 103.

Erie.—November 15, 1921, Erie Public Library. Joint meeting with Engineers Society of Northwestern Pennsylvania. Subject: "Steam Railroad Electrification." Speaker: Mr. S. T. Dodd, of the General Electr c Company, Schenectady. The talk was concluded with a film showing traction tests of electric locomotives. Attendance 190.

Fort Wayne.—November 17, 1921, G.-E. Club Rooms. After a radio-phone concert, Mr. W. R. G. Baker, of the General Electric Company, Schenectady, presented an interesting paper on "Radio Telephony", illustrated by numerous lantern slides showing the characteristics of the radio-phone circuits and apparatus. The slides also included views of obsolete and modern equipment produced by the General Electric Company during the war and at the present time. Actual installations in both aeroplanes and submarines were also shown Mr. M. Putt, of the Fort Wayne Works, set up his transmitting and receiving set in the room and was able to transmit and receive radiophone conversation with Mr. George Bowers one of the local amateurs. Refreshments were served. Attendance 125.

Indianapolis-Lafayette. — November 16, 1921, Claypool Hotel. Subject: "Problems in the Consolidation of Automatic and Manual Telephone Plant for Interchange of Service." Speaker: Mr. W. E. Darrow, of the American Telephone & Telegraph Company, New York City. Attendance 69.

Ithaca.—October 27, 1921, Franklin Hall, Cornell University. Subject: "Controllers." Speaker: Professor V. Karapetoff. A report of the A. I. E. E. June Convention was made by Mr. J. G. Pertsch, Jr. Attendance 90.

November 18, 1921, Franklin Hall, Cornell University. Subject: "Wireless Telegraphy." Speaker: Mr. W. C. Ballard. Attendance 200.

Kansas City.—November 25, 1921. Joint with local Section of the A. S. M. E. Subjects: "The Development and Designing of Diesel Engines," by Mr. C. E. Beck, of Bush, Sulzer Bros. Diesel Eng. Co.; "Operation and Economies of the Diesel Engine," by Mr. S. A. Hadley, of McIntosh and Seymour. Attendance 38.

Lehigh Valley.—November 10, 1921, Nazareth Inn, Nazareth, Pa. The meeting was preceded by a dinner. Subjects: "Motor Control Apparatus" (illustrated), by Mr. C. H. Wilhams, of General Electric Company, Philadelphia, particular stress being laid upon the applications of this equipment as applied to the cement industry; "Number of Kilowatt-Hours Consumed in the Production of a Barrell of Cement in Plants of Various Kinds and Output," by Mr. S. H. Harrison, of the Vulcanite Portland Cement Company, Easton, Pa. Attendance 98.

Los Angeles.—November 22, 1921, Assembly Room, Edison Building. Subject: "The Electric Furnace." Speaker: Mr. Mr. H. L. Todd, of the Union Tool Company of Torrance. A moving picture entitled "Rolling Steel by Electricity" was shown. Attendance 65.

Lynn.—November 2, 1921, Classical High School Hall, Lynn. Ladies and Guests Night. Subject: "Riding the Plains with the Royal Northwest Mounted Police." Speaker: Captain Daniel MacKay, of the Royal Northwest (Canadian) Mounted Police. Attendance 1000.

November 16, 1921, General Electric Hall, Lynn. Subject: "Some Mechanical Analogies in Electricity and Magnetism." Speaker: Prof. W. S. Franklin, Dept. of Physics, M. I. T. Professor Franklin explained very clearly several difficult points in electricity and magnetism. He used a large number of mechanical devices for visualizing the mechanical analogies existing in the phenomena of electricity and magnetism. Refreshments were served. Attendance 250.

December 1, 1921, General Electric Hall, Lynn. Subject: "Recent Developments of Radio Telephony." Speakers: Dr. V. Bush, of the American Radio and Research Corporation, and Mr. B. R. Cummings, of the General Electric Company, Schenectady. Mr. Cummings lecture was illustrated by a large number of lantern slides on which he showed various types of tubes and their application to radio telephony. Dr. Bush had a large amount of apparatus with which he illustrated his half of the lecture. During the course of the evening a radio concert was picked up by wireless apparatus which Dr. Bush brought with him. Attendance 375.

Minnesota.—November 28, 1921, Auditorium of Main Engineering Building, Minneapolis. Subject: "Recent Developments of the the Vacuum Tube and High-Tension Current and Their Practical Application in X-ray Apparatus and Modern Medicine." Speaker: Dr. J. Mutscheller, of the Wappler Electric Company, New York. The speaker took up important applications of X-rays radiographic, physical and engineering requirements for the design of X-ray Apparatus, and discussed in detail different types of apparatus. The lecture was illustrated with lantern slides and a moving picture film. Attendance 350.

Philadelphia.—November 14, 1921, The Engineers' Club of Philadelphia. The meeting was preceded by a dinner Subject: "The One Best Way to do Work." Speaker: Mr. Frank B. Gilbreth, of Montclair, N. J. Attendance 74.

Pittsburgh.—November 17, 1921, Chamber of Commerce. Subject: "California Power Developments." Speaker: Mr. A. W. Copley, of the Westinghouse Electric & Manufacturing Company. The lecture was illustrated with a number of slides showing the various hydroelectric installations now in operation or under construction in different parts of California. Attendance 198.

Pittsfield.—November 3, 1921, G. E. Auditorium. Preceding the meeting the speaker and guests were entertained at dinner in the South Street Inn. Subject: "Einstein's Theory of Relativity." Speaker: Dr. Charles P. Steinmetz. Before the close of the meeting refreshments were served. Attendance 350.

November 17, 1921, High School Auditorium. Preceding the meeting, dinner in honor of the speaker at the South Street Inn. Subject: "Twice Born Men." Speaker: Mr. Harry Collins Spillman, of New York, Educator and Lecturer. Attendance 400.

December 1, 1921, G. E. Auditorium. Preceding the meeting the speakers and guests were entertained at dinner given at the American House. Second lecture of a series on "Einstein's Theory of Relativity," by Dr. C. P. Steinmetz. Attendance 200.

Portland.—November 15, 1921, University Club. Mr. Chas. A. McCune, of the Page Steel and Wire Company, New York City, presented a series of motion pictures on "Making Armco Iron and Welding Rods." Mr. R. V. Barker of the General Electric Company, presented a number of lantern slides showing automatic arc-welding machines and the work performed by them. Refreshments were served. Attendance 78.

Providence.—December 2, 1921, Rooms of Providence Engineering Society. Subject: "Recent Developments in Electrolysis Testing." Speaker: Mr. E. R. Shepard, of the Bureau of Standards. Attendance 55.

Rochester.—November 25, 1921. Subject: "Recent Advances in Long Distance Communication." Speaker: Mr. H. E. Shreeve, of the Western Electric Company. The speaker described the work in connection with the Transcontinental line from New York to San Francisco, the difficulties encountered and how they were overcome the use of the loading coil, telephone repeater, etc. Attendance 90.

Schenectady.—December 2, 1921, Edison Club Hall. Subject: "The Superpower System as an Answer to a National Power Policy." Speaker: Mr. W. S. Murray of New York. The speaker discussed the purpose and general results obtained by the Superpower Survey, pointing out the many valuable features of such a system. In addition he gave a general review of the superpower report as now published. Attendance 280.

Seattle.—November 15, 1921, Subject: "Development studies Affecting Telephone Plant Design." Speaker: Mr. W. C. Pickford, Division Commercial Engineer, of the Pacific Telephone & Telegraph Company. Attendance 55.

Spokane.—December 2, 1921, Davenport Hotel. Subject: "Operation of the Electrified Coast Division of the Chicago, Milwaukee & St. Paul Railway." Speaker: Mr. R. B. Childs, Superintendent of the Intermountain Power Company, Seattle. Attendance 28.

Syracuse.—November 18, 1921, Syracuse University. Subject: "A. I. E. E. Convention, Salt Lake City." Speaker: Professor Rich D. Whitney. Attendance 12.

Toronto.—November 11, 1921, Toronto University. Subject: "Series vs. Multiple Street Lighting Systems." The meeting took the form of an open debate, the subject being first introduced by five chosen speakers. Attendance 79.

November 25, 1921, Toronto University Subjects: "The Bristol Pyrometer" by Mr. H. L. Griggs, of the Bristol Company; and "Recording Instruments" by Mr. M. J. Johnson, also of the Bristol Company. Attendance 88.

Urbana.—November 22, 1921. Subject: "The Caribou Hydroelectric Development in the Sierra Nevada Mountains" (illustrated with motion pictures and colored slide). Speaker: Mr. A. A. Northrop, of Stone and Webster, Inc. Attendance 225.

Utah.—November 18, 1921, Commercial Club. Subject: "Characteristics an Engineer may well Possess." Speaker: Mr. O. B. Coldwell, Vice-President A I. E. E. Attendance 59.

Vancouver.—December 2, 1921, Board of Trade Auditorium. Subject: "Application of the Electron Theory to Modern Electrical Development." Speaker: Mr. J. G. Lister, Principal, Vancouver Technical School. Attendance 31.

Washington, D. C.—November 8, 1921, Cosmos Club. Subjects: "The Hydroelectric Developments of the Pacific Coast (illustrated with slides) by Prof. L. D. Bliss; "The Operation of an Eastern Hydroelectric Plant" by Mr. A. F. Bang; of the Pennsylvania Water Power Company; "The Comparative Costs of Operation of Hydroelectric and Steam Electric Plants" by Mr. C. E. Oakes, of the Federal Power Company. Attendance 158.

Worcester.—November 17, 1921, W. P. I. Joint meeting with local Section A. S. M. E. Four p. m., inspection of Webster Street Plant of the Worcester Electric Light Company, attendance 125; 6.30 p. m., supper at State Mutual Restaurant, attendance 68; 8.00 p. m. meeting at Lecture Hall, W. P. I. Subject: "Colfax Power Station of Duquesne Light Company, Pittsburgh." Speakers: Messrs. G. W. E. Clarke and D. L. Galusha, of Dwight P. Robinson & Company, Inc., New York City. The paper was illustrated by two reels of motion pictures and one hundred and fifty lantern slides. Attendance 226.

BRANCH MEETINGS

Alabama Polytechnic Institute.—November 17, 1921. Subject: "Switchboards." Speaker: Mr. J. K. Woolfolk, of the Westinghouse Company. Attendance 46.

December 1, 1921. Subject: "Vacuum Tubes." Speaker: Mr. Julian C. Bailey, Sr. Elec. Engr. Attendance 15.

University of Arizona.—November 2, 1921. Subjects: "The Works and Ideals of the A. I. E. E.," by Professor Cloke; "Colorado River Project," presented by M. J. Erb; "My Summer Experiences with the Tucson Gas, Electric Light and Power Company" by Peny Spafford; "Marine Electrification," presented by J. Mellen (material gathered from A. I. E. E. JOURNAL). Attendance 30.

November 30, 1921. Election of officers as follows: Chairman Joseph Mellen; Secretary, H. W. Holt. Subjects: "Hayden and Inspiration Power Plant," by B. M. Davis; "Roosevelt Dam Hydroelectric Plant," by C. E. Simonds; "Phoenix Electric and Gas Plant," by W. M. Hedgepeth; "Points on Wireless," by C. C. Whysall Attendance 25.

University of Arkansas.—November 15, 1921. Illustrated lecture on "The Development of the Electrical Industry" (supplied by the General Electric Company.) Attendance 17.

November 29, 1921. Subjects: "Electrical Safety in the Utility," by B. R. Askew; "Electrical Safety in the Electrical Manufactures," by W. L. Teague; "General Safety for the Factory Worker," by H. W. McKinley. Attendance 12.

Armour Institute of Technology.—November 22, 1921. Subject: "Trip Through a Modern Railway Substation" (illustrated). Speaker: M. C. Kramer. Attendance 43.

Brooklyn Polytechnic Institute.—November 18, 1921. Joint meeting with local branch A. S. M. E. Subject: "The Future of Technically Trained Men." Speaker: Mr. Comynis, of the Alexander Hamilton Institute. Attendance 200.

Bucknell University.—December 5, 1921. Moving picture films were shown, as follows: "Queen of the Waves" (G. E. Co.); "Bryond the Microscope" and "Electrification of the Railroad" (Westinghouse Co.) Attendance 200.

California Institute of Technology.—November 9, 1921. Subject: "The Boulder Canyon Project and the Colorado River Development." Speaker: Mr. H. C. Gardett, of the Bureau of Power and Light, City of Los Angeles. Attendance 55.

University of California.—November 9, 1921. Subject: "The Relation of Industrial Accident Commission to Electrical Engineering." Speaker: Mr. F. A. Short, Electrical Engineer

for the Industrial Accident Commission of California. Attendance 20.

December 6, 1921. Election of officers as follows: Chairman, F. A. Polkinghorn; Vice-Chairman, H. R. Berry; Secretary, S. R. Ruby; Treasurer, R. A. Hall. Attendance 25.

Carnegie Institute of Technology.—December 1, 1921. Subject: "The Use of the Kelvin Double Bridge in Alternating Current Measurements." Speaker: Professor William R. Work, of the Electrical Department. Attendance 93.

Case School of Applied Science.—December 6, 1921. Subject: "Merchandising Electrical Service." Speaker: Mr. J. E. North, Treasurer, Electrical League of Cleveland. Attendance 33.

University of Cincinnati.—November 7, 1921. Subject: "The Causes of the Present Hard Times." Speaker: Professor N. H. Whitney. Attendance 70.

November 14, 1921. Subject: "What the Botanist is doing for Civilization." Speaker: Professor C. H. Benedict. Attendance 58.

November 21, 1921. Subject: "The Magnetron." Speaker: Mr. B. B. Minnium, E. E. '22. Attendance 51.

Clemson Agricultural College.—October 4, 1921. Election of officers as follows: Chairman, J. R. Reardon; Secretary, J. R. Rosa; Treasurer, E. J. Freeman. Attendance 15.

October 28, 1921. Subjects: "Radio Telegraphy" by W. F. Godfrey; "Importance of Membership in a National Society," by W. M. Riggs. Attendance 60.

November 1, 1921. Subjects: "Extracts from a Lecture on Lightning, by Dr. Steinmetz." treated by L. Miley; "Advancement of Electric Lights," treated by H. E. Nettles; "Current Events," by F. E. Thomas; demonstration of Mercury Arc Light, by Professor F. T. Dargan. Attendance 15.

November 15, 1921. Subjects: "Colfax Power Plant of the Duquesne Power Company," treated by Messrs. Tyler, O'Neill and Williams; "Current Events" by B. F. Duckworth. Attendance 15.

Colorado State Agricultural College.—November 1, 1921. Election of officers as follows: Chairman, Percy Garrett; Vice-Chairman, George Zacharisen; Secretary, Frank Ayres. Attendance 13.

November 14, 1921. Subject: "The Colorado River Power Project." Speaker: Professor Gordon. Attendance 12.

University of Colorado.—December 8, 1921. Subject: "Heating Problems of Electrical Machinery." Speaker: Mr. J. A. Elzi, member of the faculty. Attendance 25.

Iowa State College.—November 9, 1921. Subject: "Vacuum Tubes." Speaker: Professor L. F. Wood. Attendance 80.

November 30, 1921. Subjects: "Storage Batteries," by Orville E. Raffensperger, E. E. '22; "Conductors," by Quintin C. Teich, E. E. '22; "Giant Turbines," by Arthur S. Egulf, E. E. '22. The following General Electric Company films were shown: Process of Making Storage Batteries; The making of Lamp Cord; and Giant Turbines. Attendance 58.

State University of Iowa.—December 7, 1921. The following papers were read: "Cooling Transformers," C. N. Lauritsen; "Possibilities and Uses of Trolleys in the Lumber Industry," G. H. Cheek; "Trouble Shooting in Telephone Work," C. W. Longerbeam. Attendance 31.

Kansas University.—December 1, 1921. Subject: "The Application of Automatic Switching Equipment." Speaker: Mr. W. C. Looney. Attendance 37.

University of Kentucky.—October 3, 1921. Election of officers as follows: Chairman, Thomas M. Riley; Vice-Chairman, David L. Thornton; Secretary-Treasurer, Raymond H. Craig. Attendance 34.

October 31, 1921. Subject: "The Southern California Edison System." Speaker: Professor E. A. Bureau. Attendance 34.

Lehigh University.—November 11, 1921. Subjects: Salesmanship," by C. Ide '22; "Central Station Practise," by E. M. Gilbert. Attendance 64.

Lewis Institute.—December 2, 1921. Inspection trip. The senior and junior engineers made a trip to the sanitary district of Chicago Hydroelectric Power Plant at Lockport, Ill. Attendance 40.

Massachusetts Institute of Technology.—October 20, 1921. Mr. J. W. Allen, of the Boston Elevated Railway Company, gave an outline of the workings of the railway company. Attendance 80.

November 17, 1921. Subject: "Research and Education." Speaker: Professor C. A. Adams, of Harvard University. Attendance 45.

Michigan Agricultural College.—November 29, 1921. Subject: "The Trend of Modern Engineering." Speaker: Prof. Andres, of the Automatic Electric Company, of Chicago. Attendance 90.

University of Michigan.—November 30, 1921. Subject: "Meter Practise." Speaker: Mr. A. S. Albright, of the Detroit Edison Company. Attendance 70.

University of Minnesota.—December 5, 1921. Subjects: "The A. I. E. E. Movement," by W. M. Nielsen; "My Summer's Work," by W. C. Bosshardt. The General Electric film "Queen of the Waves" was shown. Refreshments were served. Attendance 31.

University of Nebraska.—November 22, 1921. Messrs. O. E. Edison, G. L. Woodworth, Seymour Sexton and G. E. Spethman spoke on their summer's experiences with the Northwestern Bell Telephone Company at Omaha. Attendance 26.

University of North Carolina.—November 17, 1921. Subjects: "Obtaining a High Vacuum," by D. A. Wells; "The Contracting Engineer," by B. E. Humphrey; "The Wireless Telephone," by G. F. Seyffert. Attendance 57.

December 1, 1921. Subjects: "The Roll of Research," by P. M. Gray; "Telephone Lines," by E. E. Dellinger; "Electrical Merchandising," by J. B. London. Attendance 40.

University of Notre Dame.—December 5, 1921. Subjects: "Electrolysis in Underground Mains," by George Stock; "Lightning Arresters," by John Fitzgerald. Attendance 30.

Ohio State University.—November 30, 1921. Illustrated lecture entitled "Electric Traction." Attendance 40.

Oklahoma University.—November 17, 1921. Subjects: "Development of the Electrical World," by J. P. Jones; "Electricity, the Wonder Worker," by W. Reilly; "Resuscitation from Electric Shock," by C. Roush. Attendance 34.

Purdue University.—October 25, 1921. Subject: "Radio Telegraphy and Its Applications." Speaker: Mr. H. T. Budenbom (Senior E. E.). Attendance 81.

November 8, 1921. Professor A. N. Topping gave a short talk on the organization of the A. I. E. E. A General Electric Company film entitled "The Production of Cotton" was shown. Attendance 122.

Rose Polytechnic Institute.—November 22, 1921. Subjects: "X-rays" and "Application of Small Motors." Speaker: Professor Knipmeyer. Attendance 31.

November 29, 1921. Subject: "Application of Electricity in Industrial Heating." Speaker: Professor Knipmeyer. Attendance 27.

December 8, 1921. Subject: "The Theory, Operation and Care of Storage Batteries." Speaker: Professor Knipmeyer. Attendance 33.

Stanford University.—November 16. 1921. Subject: "The Development of the Caribou Power Project." Speaker: Mr. J. A. Koontz, of the Great Western Power Company. Attendance 65.

Syracuse University.—November 3, 1921. Subject: "Electrocommunication." Speaker: Mr. Russell E. Hanford. Attendance 9.

November 10, 1921. Subject: "Electrification of Railroads." Speaker: Mr. P. L. Pavia. Attendance 7.

December 1, 1921. Subject: "Electric Furnaces." Speaker: Mr. P. J. Ryan. Attendance 9.

December 8. 1921. Subject: "Reversing Motor." Speaker: Mr. Robert J. Swackhomer. Attendance 12.

Texas A. & M. College.—November 2, 1921. Subject: "Resuscitation from Electric Shocks." Speaker: Jack Cruickshanks. Attendance 64.

University of Texas.—November 14, 1921. Subjects: "Junior Work with the General Electric Company," by J. E. Love, Jr.; "Some Things the Young Engineer may Expect to Encounter," by Albert Lee O'Banion; "Advantages of Belonging to the A. I. E. E.," by F. J. Domingues. Attendance 20.

University of Virginia.—December 2, 1921. Subjects: "The Aims of the A. I. E. E. and the Advantages of Being a Member," by Professor Rodman; "The Locomotive Booster," by Professor Hancock. Attendance 29.

State College of Washington.—October 28, 1921. Talk on the General Electric Testing Course by C. Guse '19. Attendance 16.

University of Washington.—December 6, 1921. Subject: "What Are You Going To Do With It—Your Engineering Education." Speaker: Mr. G. E. Quinan, of the Puget Sound Light & Power Company. Attendance 43.

West Virginia University.—November 14, 1921. Subjects: "The Magnetron," A. C. Price; "The Heating of Underground Cable," A. T. Richards; "The Economies of Melting Brass Electrically," C. Snyder; "Lighting without Hanging Ceiling Fixtures," W. D. Stump; "The Lafayette Radio Station," L. D. Tabler; "The Epoch Making Discoveries of the Years 1819-1920," J. R. Cook; "The Tendencies of Electric Lighting," C. R. Lowe. Attendance 25.

November 30, 1921. Subjects: "Automotive Generators and Their Regulation," H. Chandler; "Resuscitation from Electric Shock," I. O. Meyers; "The Public Service Commission of W. Va.," Gifford Nease; "Electric Devices Used in Blasting and Firing Explosives," Robert K. Park; "Lightning. Nature and Units Involved," C. D. Ernest. Attendance 24.

December 5, 1921. Subjects: "Research," J. L. Hark; "Corpuscular Theory of the Aurora Borealis," L. T. Faulkner; "Electric Ship Propulsion," H. C. Daniels; "Oxide Film Lightning Arrester," Lloyd Porter; "The Electric Fish Barrages." Attendance 25.

University of Wisconsin.—October 19, 1921. Talk by Professor Bennett on the "Electrical Show" to be put on by the students during the year. Attendance 19.

November 2, 1921. Subject: "Automatic Substations." Speaker: A. R. Cotton. Attendance 18.

Yale University.—November 30, 1921. Joint meeting with local Branches of A. S. M. E. and A. S. C. E. Subject: "The Caribou Hydroelectric Development of the Great Western Power Company of California." Speaker: Mr. Albert A. Northrop of Stone & Webster Engineering Corporation. Attendance 125.

Employment Service Bulletin

OPPORTUNITIES.—Desirable opportunities for service from responsible sources are announced in this Bulletin, and no charge therefor is made.

MEN AVAILABLE.—Under this heading brief announcements (not more than fifty words) will be published without charge to the members. Announcements will not be repeated except upon request received after a period of three months, during which period names and records will remain in the active files.

NOTE.—Notices for the JOURNAL ***should be addressed to EMPLOYMENT SERVICE, 33 West 39th Street, New York, N. Y.,*** *the employment clearing house of the Societies constituting the Federated American Engineering Societies, and* ***not*** *to the A. I. E. E.*

Notices for the JOURNAL are not acknowledged by personal letter, but if received prior to the 16th of the month will appear in the issue of the following month.

All replies to either "Opportunities" or "Services Available" should be addressed to the key number indicated in each case ***and forwarded to EMPLOYMENT SERVICE, as above.***

Replies received by the bureau after the position to which they refer has been filled will not be forwarded, and will be held by the bureau for one month only.

Information regarding the notices published is on file in the offices of the member societies of the Federated American Engineering Societies.

POSITIONS OPEN

TRANSMISSION LINE SUPERINTENDENT. Applicant must be conversant with practise in transmission lines, 100,000-volt, three-phase, 50-cycle. Must be capable of taking entire charge of transmission system of approximately 400 miles of line, must be familiar with both construction and operating work, and must be capable of handling native help. Reply stating age, experience, training and salary desired. Location India. X-1292.

ASSISTANT PROFESSOR IN ELECTRICAL ENGINEERING for the second term of the school year. Work begins February 1st. Possibilities of continued appointment. Prerequisites—teaching and practical experience, character, personality and executive ability. Location, East. X-1328.

INSTRUCTOR IN ELECTRICAL ENGINEERING for the second term of the school year. Work begins February 1st. Possibilities of continued appointment. Prerequisites—teaching and practical experience, character, personality and executive ability. Location, East. X-1329.

SALES EXECUTIVE. Public Utility company operating in large territory near New York, is seeking the services of an executive who can qualify as a rate analyst in the field of gas and electrical rates and combine the executive ability necessary to direct a sales organization. College graduates preferred. Position warrants large salary and offers an exceptional opportunity for extra compensation based on future growth. Communications are wanted only from men who are clearly qualified by character and ability. X-1386.

ELECTRICAL ENGINEER graduate with between two and five years experience on relays, substations, switchboards, switchboard designing, substation designing and remote control experience. Location, Pa. X-1388.

OPERATING MAN with between two and five years experience in substation operation, and cable experience. Location, Pa. X-1389.

ELECTRICAL DRAFTSMAN. Prefer young American with good technical education and sufficient practical drafting experience on mechanical details and layout of d-c. and a-c. motors to enable him to be immediately serviceable in same line of work. Location, Chicago, Ill. X-1403.

STEAM & ELECTRICAL ENGINEER. Must be capable of designing steam and electrical apparatus, design and installation of power plant equipment, capable of making boiler and electrical tests and to recommend electrical equipment, boilers and engines for various requirements, to make studies, charts, etc. on fuel and power, waste gases, and steam losses. Must be familiar with electrical and steam applicances and equipment. Member A. I. E. E. preferred. Application by letter. Send photograph and complete record of experience. Location, Ohio X-1413.

SEVERAL YOUNG ELECTRICAL ENGINEERS to act as meter readers or test men on electrolysis investigation work. Must have had actual experience in this work. Application by letter only. Location, Chicago, Ill. X-1476.

ELECTRICAL ENGINEERS with practical experience in electrolysis work. Application by letter only. Location, Chicago, Ill. X-1477.

ELECTRICAL ENGINEER with radio sales experience. Must know radio trade in U. S. No position at present but will open department if man with this experience can be found. Location, New York City. X-1485.

INSTRUCTOR who can teach applied mechanics, hydraulics, and laboratory. Prefer one who is well up in theory, especially in mathematics and mechanics. Knowledge of accounting will be advantageous. Work will begin about the first of February. X-1489.

LINEMEN who have had experience in general line construction and maintenance and in hot line work at high altitudes. We have a 50,000-volt line of the pin type. X-1496.

ELECTRICAL ENGINEER to make inspection of electrical equipment of power plants and industrial plants. Should have about two years experience in the service department of either General Electric or Westinghouse doing erection and repair work. Location, Boston and New York. X-1397.

ENGINEER experienced in the design of a-c. and d-c. motors (up to 40 h. p.). Location, New Jersey. X-1510.

ELECTRICAL ENGINEERING GRADUATE for position as sales engineer with large Electrical Manufacturing concern in Middle West. Splendid opportunity for right man. State age and qualifications in detail in the first letter. X-1520.

MEN AVAILABLE

DISTRIBUTION ENGINEER—Ten years experience in the generation, transmission and distribution of power. Experienced in the sale of power and general business. At present superintendent of company handling 15,000-kw. hydroelectric plant. Wider experience desired. Would accept similar position in any country. British subject, 30 years, married, perfect health. E-3113.

ENGINEER with 25 years experience in designing, constructing and managing hydroelectric and allied properties available for employment in foreign countries. E-3114.

ELECTRICAL ENGINEER—College graduate, 2 years G. E. Test, 11 years designing engineering experience, four years in mining and steel mill work. Expert in mining work. American, salary $3500 to $4000, available at once. E-3115.

ELECTRICAL ENGINEER — Member of A. I. E. E. Age 37, married. Four years design of central battery telephone equipment. Seven years sales engineering. Four years power engineering, including hydraulic design, electrical and mechanical design 165,000-volt transmission lines, power houses and substations. Good executive, can handle men. Studying Spanish. Would like position in South America or other foreign country. Large hydroelectric work now employed on, nearing completion. Available on 30 days notice. E-3116.

EXECUTIVE, ELECTRICAL ENGINEER—Technical graduate, member A. I. E. E. Thirteen years experience in design and operation of electrical machinery, central station operation and distribution and sales engineering. Available short notice. Full details immediately available. E-3117.

GRADUATE ELECTRICAL ENGINEER—Age 25, married, desires position with chance for advancement. 1½ years experience engineering department company manufacturing physiotherapy and X-ray equipment. Experience with ultra-violet apparatus such as used in water sterilization. Familiar with recent developments in actino-therapy. E-3118.

ELECTRICAL ENGINEER, technical graduate Assoc. A. I. E. E. Age 28, 6 years experience in testing laboratory, radio, chief engineer of marine installation and maintenance, remote control, machine tool application, estimating and construction work. Desires permanent position with well established company, planning, estimating and following up progress of jobs. Location preferred Newark or New York City, available one month. E-3119.

ENGINEER—A combination of work that requires commercial knowledge and taste, combined with a technical electrical education is my specialty. Four years experience in the manufacture, installation, and sales of electrical machinery. Best of references from all past connections as to character and ability. Age 23. Free to travel. E-3120.

POWER AND MECHANICAL ENGINEER—technical graduate, B. S. and M. E. Age 30, single, eight years experience along broad lines, machine shop, metallurgical, chemical manufacturing, sugar engineering, industrial and power plant practise, operation, design, layout, heat balance, calculations, steam and water distribution and utilization of wastes, etc. Good executive ability; desires responsible position. E-3121.

RECENT ELECTRICAL ENGINEERING GRADUATE—Age 24; single; 9 months practical experience in power-house construction work, wishes position with public utility company, electrical construction company, or manufacturing concern. Energetic and ambitious worker. Location anywhere. E-3122.

ELECTRICAL ENGINEER—age 24, single. Desires position with engineering or manufacturing company, where responsibility, industry and engineering ability is required, and where opportunity for advancement exists. Nine months General Electric testing experience. E-3123.

WANTED—an interview and chance to submit my references from present and past employers. Graduate electrical engineer. Age 33. Married. Manager or superintendent of construction or operation. Proved ability to handle men, get results and save money. Industrial, railroad and light and power experience. Available January 15, 1922. E-3124.

SUPERINTENDENT OF OPERATION for high-voltage transmission system, technical graduate, six years experience operation and maintenance of 100-kv., 60-kv., 22-kv., transmission system and substations; formerly captain A. E. F. At present assistant superintendent of operation for large southern system; desires change; salary $4500. E-3125.

ELECTRICAL ENGINEER—Single, age 23, E. E. degree, one year General Electric Company test, desires a position with good chances for advancement. Location N. Y. State. E-3126.

TECHNICAL GRADUATE—Age 28, with initiative and the ability of leadership desires position with manufacturing concern. Small practical experience, but four years business training along financial and sales lines. Good knowledge of Spanish. Opportunity, not immediate salary, primary consideration. Prefer New York, but will go where opportunity calls. E-3127.

PROFESSOR OF ELECTRICAL ENGINEERING—Just completing some commercial work which has occupied the last three years. Previous position as professor, for fifteen years, in one of our large Universities, teaching both elementary and advanced electrical work. Special engineering jobs during vacations. Available Feb. 1st, 1922, if necessary. Thoroughly conversant with both theory and practise. Prefer educational work. E-3128.

MECHANICAL AND ELECTRICAL ENGINEER—Graduate 1910, eleven years experience with the leading American and European companies in most efficient methods of design, layout, estimating and construction of electric power and light installations. Available January 15th. E-3129.

ELECTRICAL AND MECHANICAL DRAFTSMAN—Age 23, eight years experience on switchboard and power house equipment, (four years installing, four years drawing office) undergraduate electrical engineering night course, A1 knowledge and experience in power house diagrams and outdoor substation layouts. Desires position in engineering or drawing office in western Pennsylvania. Assoc. A. I. E. E. Available short notice. E-3130.

NEW BUSINESS MANAGER—Technical graduate in Electrical Engineering, with 12 years varied experience in public utility and industrial engineering, seeks connection with concern in a business and territory permitting growth. Available on reasonable notice. Married. Location East of Mississippi and North of Dixie Line. E-3131.

ELECTRICAL ENGINEER — University, technical graduate with three years experience, desires connection that will help fit him to become a consulting engineer or a business executive. Additional information sent on request. E-3132.

MANAGEMENT—Am interested in managing electric light and power company in small or medium-size town and place on paying basis. If proper opportunity offered would give up responsible position in large city as prefer living in smaller town. Member A. I. E. E. Age 35. E-3133.

FACTORY EXECUTIVE AND INDUSTRIAL ENGINEER—Age 41, with practical and technical training and experience in investigations, planning, routing cost and production work, wishes suitable position with manufacturing concern. E-3134.

ELECTRICAL-MECHANICAL ENGINEER—M. I. T. graduate, 10 years experience designing, testing, sales and executive work on equipment for power and industrial plants. N. Y. preferred. E-3135.

GRADUATE ELECTRICAL ENGINEER—age 32, married, for four years research engineer with foremost maker of electrical measuring instruments, desires change. Prefers to take complete charge of small research or standardizing laboratory, but will consider any technical position with responsibility and future. E-3136.

ENGINEER—Assoc. A. I. E. E. available at once. Five years on construction work, power house and transmission. Three years on sales. One and one half years manager public utility operating both steam and hydroelectric power. About three years as superintendent of power, large utility with hydroelectric and steam power, 25,000 kw. and 400 miles transmission lines. E-3137.

GRADUATE ELECTRICAL ENGINEER—B. S. E. E. degree. Age 23. Single. Six months G. E. test. Desires position where hard work and ability are recognized by proportionate advancement. Southern location preferred. E-3138.

ELECTRICAL ENGINEER—College graduate 1921, interested in power work, desires position with engineering or power company involving some outside work. Hydroelectric, central station or electric railway work preferred. Two summers spent in power work. Location immaterial. E-3139.

ELECTRICAL ENGINEER—20 years experience in design of all kinds of d-c. generators and motors, also experience in fractional horse power a-c. motor design. Know manufacturing and testing and all detail troubles thoroughly. Know materials and how to use them. Can instruct all workers in the manufacturing operations. E-3140.

SUPERINTENDENT—Successful organizer and executive with thorough practical public utility experience. Past experience in management and supervision of steam and hydroelectric construction, operation and maintenance. Desires similar position, where hard work and initiative are the essential requirements. Available on short notice. Married. Age 30. E-3141.

ASSISTANT OR SECRETARY to consulting or production engineer. B. S. E. E. degree.

Experienced office executive and correspondent. Familiar with bakelite insulation products, electrical testing, handling of orders, contracts, domestic and foreign shipments. Expert shorthand writer and typist. Age 28. Single. Christian. Excellent references. At present employed. Salary $2500. E-3142.

ELECTRICAL ENGINEER—With 17 years practical experience in industrial plant, repair shop, testing trouble and installation work out on the road. Can furnish best of references, prefer New Jersey or New York. Age 34, married, available 30 days, salary $2600 minimum. E-3143.

ELECTRICAL ENGINEER AND ESTIMATOR—Technical graduate of exceptional ability, desires position with an established consulting engineering or contracting firm. 4½ years electrical contracting experience, six years with large engineering firm making plans and writing specifications for electrical equipment of all classes of buildings. Executive ability, ambitious and courteous. Can take full charge of work and produce results. E-3144.

DRAFTSMAN—Technically trained young man with five years experience on light and power layouts, switchboard and power plant design and test work; desires drafting or laboratory position. Formerly with corporation building high-tension electrically driven ships. E-3145.

ELECTRICAL ENGINEER—6 years with one of the largest manufacturers of enclosed fuses, cutouts, etc. In charge of all experimental and development work. 28 years of age, married. American. Available after Jan. 1st. E-3146.

ACCOUNTANT ENGINEER—Three years experience on construction and operation of hydroelectric and steam plants and high-tension lines and apparatus. Two years experience valuation and appraisals of light and power companies and street railways. Five years experience as an accountant. Alexander Hamilton Course. Age 28. Married. New England States E-3147.

GRADUATE ELECTRICAL ENGINEER—Massachusetts Institute Technology, five years supervision engineering practise, two years executive work overseas, present manager small electrical manufacturing company, desires change for broader field of activity; manufacturing or industrial development; initiative, perseverance, coupled with training and character, developing a person YOU can depend upon; age 32, married; present salary rate $3000; available on reasonable notice.

COMMERCIAL ENGINEER—(Electrical) Honor graduate 1918, degree B. S., Commissioned Officer, U. S. Army Field Artillery. For past three years with General Electric Company in testing, designing engineering, application engineering and commercial departments. Now in Mid-Western office of this company. Desires location in eastern city in commercial or managerial department of operating or other company of recognized standing. E-3149.

GRADUATE ELECTRICAL ENGINEER, degrees in mechanical and civil engineering, five years experience in responsible mechanical and electrical design work and trusted with executive and factory duties. Possesses good share of common sense and splendid personality. Age 27, nationality, American. Desires position in vicinity of New York City. Employed at present but desires change. E-3150.

CONTRACTORS AND CONCERNS dealing with same, can possibly make use of the services of a technically trained man, 24 years old with intensive experience in contractors office and in the field. Work of selling nature in conjunction with engineering preferred. E-3151.

YOUNG MAN—24. Good technical training and initiative. E. E. degree 1921, wishes position with future. Some testing experience. Manufacturing, testing, or similar work considered. E-3152.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED DECEMBER 9, 1921

AMSTUZ, J. OSCAR, Electrical Draftsman, New York Edison Co., 130 E. 15th St., New York; res., 121 Prospect Place, Brooklyn, N. Y.

ARD, LIGON BRIGGS, Sales Engineer, 112 W. 59th St., New York, N. Y.

BABA, KUMEO, Chief of Design Dept., Hitachi Engineering Works, Lecturer, Tohaku Imperial University, Sendai, Japan.

BANG, CLAUS M., Electrical Designing Engineer, Wayayamack Pulp & Paper Co., Ltd.; res., 161 Avenue Laviolette, Three Rivers, Que.

BARRER, GLEN A., Erecting Engineer, General Electric Company; res., 1521 E. 65th St., Chicago, Ill.

*BIBBER, HAROLD WHITNEY, Instructor in Electrical Engineering, Massachusetts Institute of Technology, Cambridge, Mass.

BISDEE, COLIN EDWARD, Testing Dept., General Electric Company, Schenectady, N. Y.

BUCKLEY, JOHN STANLEY, Engineer, Laboratory & Meter Section, Chilian Electric Tramway & Light Co. Ltd., Santiago, Chile, S. A.

COOPER, HERBERT W., Trouble Operator, Worcester Electric Light Company; res., 447 Grove St., Worcester, Mass.

CRONSTEDT, HARRY GRAHAM, Inspector, Western Electric Company, 104 Broad St.; res., 1842 Amethyst St., New York, N. Y.

DAYMUDE, EARL LUDLOW, Draftsman Puget Sound Power & Light Company, 605 Electric Bldg., Seattle, Wash.

DE CHESNE, HERBERT E., Chief Clerk & Assistant General Storekeeper, Puget Sound Power & Light Co.; res., 940 N. 85th St., Seattle, Wash.

DELSASSO, LEO P., Assistant Protection Engineer, Southern California Edison Co.; res., 166 W. 37th St., Los Angeles, California.

EMERY, HOWARD L., Electric Meter Tester, Worcester Electric Light Company; res., 21 Fales St., Worcester, Mass.

EVANS, WILLARD MARTIN, Relay Section Foreman, Duquesne Light Company, 3708 5th Ave., Pittsburgh, Pa.

*EVENSON, FRANKLIN FENELON, Junior Electrical Engineer, City of Los Angeles; res., 1149 Coronada Terrace, Los Angeles, Cal.

FLEMING, GEORGE ADAIR, Draughtsman, Southern California Edison Company; res., 1357 W. 38th Place, Los Angeles, Cal.

FLUCK, AARON CONARD, Office Manager, Braden Copper Company, Rancagua, Chile, S. A.

*FREEMAN, NEWELL LESLIE, Instructor in Physics, Washington University; res., 2824 Park Ave., St. Louis, Mo.

FULLER, ANDREW B., Electrical & Mechanical Draftsman, Puget Sound Power & Light Co.; res., 924 60th West, Seattle, Wash.

FUNG, CHIEN, Student Engineer, General Electric Co.; res., 304 Glenwood Blvd., Schenectady, N. Y.

FURUKAWA, KOZO, Electrical Bureau of Japanese Government Railway, 1 Madison Ave., New York, N. Y.

GENTRY, BYRON WILSON, Tester, Western Electric Company; res., 7 West 95th St., New York, N. Y.

GRAY, NEWMAN D., Assistant Superintendent, Phoenix Utility Company; Bachman House, Hazelton, Pa.

HALL, CLARENCE, Tool Designer, Century Electric Company; res., 3723 Palm Street St. Louis, Mo.

HARRIS, GEORGE W., Electrical Contractor, 101 N. West St.; res., 251 W. Ostrander Ave., Syracuse, N. Y.

HAYES, JOHN J., Manager, Treasury Dept., Westinghouse Elec. & Mfg. Co., 1400 Alaska Bldg., Seattle, Wash.

HEATHERINGTON, ELMER STANDISH, Tester of Electrical Apparatus, General Electric Co.,; res., 47 Forest Place.

HILL, IRA B., Captain C. A. C., U. S. Army, Artillery Engineer, Coast Defenses of Balboa, Fort Amador, Canal Zone.

HITESHUE, GEORGE PHILIP, Laborer, Pennsylvania Rubber Company; res., 619 Division St., Jeannette, Pa.

HOFFMAN, HARRY JOHN, Sales Dept., Condit Electrical Mfg. Company, Boston; res., 8 Estrella St., Jamaica Plain, Mass.

ITO, HARRY I., Electrician, Lihue Plantation Co., Lihue, Kauai, Hawaii.

JACKSON, ALEXANDER McLEOD, Sales Engineer, Locke Insulator Corp., 721 Newhouse Bldg., Salt Lake City, Utah.

JANITSCHKE, ERICK O., Radio Draftsman, Machinery Division, U. S. Naval Station, Pearl Harbor, T. H.

JOHNSON, EMIL W., Secretary & Treasurer, Electrical Construction Co., 410 De Mers Ave., Grand Forks, N. Dakota.

JOHNSON, FREDOLPH PETRI, Testing Dept., Western Electric Company, 210 W. 36th St.; res., 7 W. 95th St., New York, N. Y.

JONS, HUGO, Draftsman, Western Electric Company; res., 4758 W. Madison St., Chicago, Ill.

KEENER, CHARLES ALVA, Instructor, Electrical Engineering Dept., University of Illinois; res., 901 W. Nevada St., Urbana, Ill.

KERR, THOMAS BISHOP, Testing Dept., Canadian General Electric Company; res. 93 Aylmer St., Peterboro, Ont., Canada.

LEHMANN, GEORGE FREDERICK, Foreman, Testing Bureau, United Railways & Electric Co.; res., 425 N. Luzerne Ave. Baltimore, Md.

LUKENS, ARTHUR THATCHER, Assistant Design Calculator, Philadelphia Electric Company, 1000 Chestnut St., Philadelphia, Pa.

MAC LEAN, DONALD; res., 25 Pierrepont St., Brooklyn, N. Y.

MAC LEOD, DONALD B., Testing Dept., British Thomson-Houston Co., Ltd.; res., 52 Craven Road, Rugby, Eng.

MARSTALL, FRANK J., Sales Engineer, Westinghouse Elec. & Mfg. Co., Union Bank Bldg., Pittsburgh, Pa.

McLEOD, ABNER A., Emergency Man, Worcester Electric Light Company; res., 7 Sturgis St., Worcester, Mass.

McMANN, RENVILLE HUPFEL, Radio Manager, Federal Telephone & Telegraph Company, Buffalo; res., 380 Riverside Drive, New York, N. Y.

MERRILL, WARREN CORNING, Switchboard Engineer, The Pacific Tel. & Tel. Co., 835 Howard St., San Francisco, Cal.

MILLER, WAYNE W., Telephone Engineer, The Bell Telephone Company of Pennsylvania, Philadelphia; res., 614 Noble St., Norristown, Pa.

*MINNICH, CHARLES T., Operator, Southern California Edison Company; res., 619 Loomis St., Los Angeles, Cal.

MORGAN, CLINTON WILKINS, Salesman, Westinghouse Elec. & Mfg. Company; res., 1281 Maryland Ave., Milwaukee, Wis.

MOUGEY, WILBUR EUGENE, Telephone & Cable Engineer, Western Electric Co., 463 West St., New York, N. Y.

MUELLER, FRANK ROBERT, Instructor, Bliss Electrical School, Washington, D. C.

*MUMMA, LEVI BUSHNELL, Senior Mechanical Engineer, Purdue University 320 Waldron St., Lafayette; Harlan, Ind.

NORBY, WALTER LEONARD, Meter Tester, Worcester Electric Light Company; res., 7 Boardman St., Worcester, Mass.

NUNN, DARRELL, Cable Engineer, Western Electric Co., Ltd., North Woolwich; res., 37 Castletown Road, London, W. 14, Eng.

PARKER, RAY D., Superintendent, Power Plant & Substations, Havana Electric Railway, Light & Power Co., Havana, Cuba.

PEACOCK, WORTH CALVIN, Consulting Engineer, Hainz Bldg., Sebring, Fla.

PHILLIPS, EMORY BERTRAM, Engineer, Western Electric Company, 463 West St., New York; res., Central Y. M. C. A., Brooklyn, N. Y.

PRENDERGAST, RALPH M., Meter Inspector, Hydro-Electric Power Commission of Ontario; res., 30 Chatham St., Belleville, Ont.

REYNOLDS, LAWRENCE HOUSTON, Chief Engineer, Acme Mfg. Company, Acme, N. C.

RODRIQUES, ALBERT A. A., General Helper, Restaurant, Western Electric Co., 463 West St., New York, N. Y.

RUSSELL, ARCHIBALD J. G., Sales Engineer, Jas. J. Niven & Co., Ltd., 160 Litchfield St., Christchurch, N. Z.

SAEVIG, THORBJORN, Manager, Aalesund Municipal Electricity Works, Aalesund, Norway.

SCHLEIGH, GEORGE HENRY, JR., Meter Man, Service Dept., Westinghouse Elec. & Mfg. Co.; res., 1614 Belasco Ave., Beechview, Pittsburgh, Pa.

*SCHMIDT, WILLIAM STOUFFER, Power Salesman, New Business Dept., Pennsylvania Public Service Corp; res., 226 Green St., Westmount, Johnstown, Pa.

SCOTT, KENNETH L., Instructor in Electrical Engineering, University of Wisconsin; res., 1019 W. Johnson, Madison, Wis.

SHEN, SHOW-LIANG, Student Engineer, International Western Electric Co., 195 Broadway, New York, N. Y.

SIEURIN, ALF EMANUEL, Inspector, Worcester Electric Light Company, 66 Faraday St., Worcester, Mass.

SLATER, EARL A., Engineer, General Engineering Dept., Westinghouse Elec. & Mfg. Co., E. Pittsburgh, Pa.

SPRARAGEN, BENJAMIN; res., Warwick, N. Y.

STEPHENSON, JOHN GORDON, Testing Dept, Canadian General Electric Company; res., 185 King St., Peterboro, Ont.

STRATTON, RICHARD de FONTAINE, Advisory Electrical Engineer, Messrs. Binny & Co., Ltd., Madras, India.

*SURANSKY, PAUL, Electrical Salesman, Fairbanks, Morse & Company; res., 2423 Post St., San Francisco, Calif.

SWEZEY, BURDETTE STEVENS, Engineer, American Tel. & Tel. Company, 195 Broadway, New York; res., 40 Shepherd Ave., Brooklyn, N. Y.

TALLA, JOSEPH, Asst. Superintendent of Power, Water Users' Association; res., 901 E. Willetta St., Phoenix, Ariz.

TURNER, DONALD LE ROY, Instructor, Bliss Electrical School, Takoma Park, D. C.

VAN DUSEN, CHARLES THERON, Rodman, New England Power Co.; Power Construction Co., Wilmington, Vt.

VINCENT, GILBERT IRVING, Engineer, Syracuse Lighting Company, 339 So. Warren St., Syracuse, N. Y.

VRLA, RALPH R., Electrical Engineer & Contractor, Taylor Instrument Company, Rochester, N. Y.

*WALKER, LEWIS BRADFORD, Student Electrical Engineer, Testing Dept., General Electric Co.; res., 230 Union St., Schenectady, N. Y.

WALTER, OTTO WALLACE, Assistant Professor of Electrical Engineering, University of Oklahoma; res., 910 Monnett Ave., Norman, Okla.

WATKINS, IRA BARTON, Division Foreman, Oklahoma Gas & Electric Company; res., 314 E. Duffy St., Norman, Okla.

WATKINS, MURDOCH M., Engineering Dept., Birmingham, Alabama, Railway, Light & Power Co.; res., 1105 North 30th St., Birmingham, Ala.

WILLIAMS, FRED M., Chief of Manual Central Office, Engineering Division, Western Electric Co., Inc., Hawthorne Station, Chicago; res., La Grange, Ill.

WISE, JOHN EDWIN, Instructor, Electrical Engineering Dept., Director, Standards Laboratory, University of Wisconsin, Madison, Wis.

WRIGHT, CLYDE GUFFEY, Chief Clerk, Substations, West Penn Power Co., Connellsville; res., 32 Second Ave., Scottdale, Pa.

WURTH, CARL WILLY; res., 39 Grace St., Bloomfield, N. J.

Total 87.

*Former enrolled Students.

ASSOCIATES REELECTED DECEMBER 9, 1921

FOREMAN, WALTER EVEREST, Sales Manager & Engineer, Railway & Power Engineering Corp., Ltd., 133 Eastern Ave., Toronto, Ont.

KRAUSNICK, WALTER, Assistant Professor of Electrical Engineering, Newark Technical School, 367 High St., Newark, N. J.

MEMBERS ELECTED DECEMBER 9, 1921

NORDIN, JOHN A., Works Manager, Stal-Turbine Co., Finspong, Sweden.

WILBRAHAM, ROSSITER W., Electrical Engineer, Day & Zimmerman, 611 Chestnut St., Philadelphia, Pa.

TRANSFERRED TO GRADE OF FELLOW DECEMBER 9, 1921

GILL, LESTER W., Professor of Electrical Engineering, University of British Columbia; Consulting Engineer, Vancouver, B. C.

GRACE, SERGIUS P., Engineer on Foreign Wire Relations, American Telephone & Telegraph Co., New York, N. Y.

TRANSFERRED TO GRADE OF MEMBER DECEMBER 9, 1921

CLARK, JAMES C., Associate Professor of Electrical Engineering, Stanford University, Stanford University, Calif.

FITZGERALD, THOMAS W., Professor of Electrical Engineering, Head of Department, Georgia School of Technology, Atlanta, Ga.

HANSON, C. F., Director of Electrical Research, Habirshaw Electric Cable Co., Yonkers, N. Y.

LANCASTER, JOHN G., Chief Electrical Engineer, Hay & Vickerman, Wellington, New Zealand.

MORGAN, THEODORE B., Asst. Supt., Southern Division, Public Service Electric Co., Trenton, N. J.

MUIRHEAD, JAMES, Government Inspector of Electrical Energy, Province of British Columbia, Vancouver, B. C.

PERTSCH, JOHN G., JR., Assistant Professor of Electrical Engineering, Cornell University, Ithaca, N. Y.

WHITEHURST, ROLAND, Manager, Washington Branch, Electric Storage Battery Co., Washington, D. C.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held December 5, 1921, recommended the following members of the Institute for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the Secretary.

To Grade of Fellow

BRIGHT, GRAHAM, Engineer-in-Charge, Mining Section, General Engg. Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

To Grade of Member

FLOYD, F. N., Assistant, Electrical Engineering Div., Dwight P. Robinson & Co., Inc., New York, N. Y.

GOLDING, JOSEPH N., Vice-President & General Manager, Mailhouse & Golding, Inc., New Haven, Conn.

HAYDEN, THOMAS J., Teacher of Practical & Applied Science, Department of Education, New York, N. Y.

LEHURAUX, LOUIS, International General Electric Co., Schenectady, N. Y.

MIRICK, CARLOS B., Vice-President, National Electrical Supply Co., Washington, D. C.

PEET, JAMES C., Professor of Electrical Engineering, College of Engineering of Newark Technical School, Newark, N. J.

SAUNDERS, LLEWELLYN, Partner, Saunders & Sorrell, Norfolk, Va.

STEWART, CHARLES C., Chief Electrical Engineer, Sinclair Refining Co., Chicago, Ill

STORY, EDWARD C., Supervising Cost Engineer, with Dr. Thomas Conway, Jr., Allentown, Pa.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before January 31, 1922.

Ahuado, Jose, Baltimore, Md.
Alder, George W., New York, N. Y.
Allen, Joseph W., Dayton, Ohio
Amerman, Albert L., Brooklyn, N. Y.
Amsden, Burton R., New York, N. Y.
Anderson, Edward B., Detroit, Mich.
Anderson, Sidney E., New York, N. Y.
Archer, John W., Pittsburgh, Pa.

Atkins, Charles E., Webster Groves, Mo.
Baer, Walter O., Milwaukee, Wis.
Bailey, George A., New York, N. Y.
Ball, Francis L., Fitchburg, Mass.
Ballenger, Albert R., Wellford, S. C.
Bauer, Louis H., Louisville, Ky.
Baulch, Bert L., Toronto, Ont.
Baxter, Charles E., Detroit, Mich.
Beardmore, Albert E., Warren, Minn.
Bell, Franklyn E., Hartford, Conn.
Bennett, John S., Chapel Hill, N. C.
Bennett, Ralph S., Pittsfield, Mass.
Bion, John W., New York, N. Y.
Blume, William E., New York, N. Y.
Bockenek, David M., Wilkinsburg, Pa.
Bowman, John D., Waterville, Me.
Brannigan, Edward J., Waterbury, Conn.
Brennan, Harold B., Schenectady, N. Y.
Brenton, Walter, Portland, Ore.
Brickson, Rolf A., Telluride, Col.
Bridges, Frank R., Boston, Mass.
Brown, John H., New York, N. Y.
Buchan, Chester E., Amery, Wis.
Buchanan, James R., (Member), Sylva, N. C.
Buehler, Fred W., Ottawa, Ill.
Bull, Edwin A., (Fellow), Chicago, Ill.
Bunting, Stephen C., Schenectady, N. Y.
Byron, John P., Seattle, Wash.
Carlson, Carl O., Newark, N. J.
Carpenter, Philip M., Hartford, Conn.
Carranza, Jesus, Mexico City, Mex.
Carroll, Jerry, (Member), Mauston, Wis.
Carson, Joseph, Boston, Mass.
Caskey, Arthur D., Chicago Heights, Ill.
Castro, Carlos, New York, N. Y.
Chisholm, Raymond D., New York, N. Y.
Chiu, Wei-Yu, New York, N. Y.
Claparols, Manuel, Wooster, Ohio
Clark, Frank L., Martinez, Cal.
Clarkson, Ben, San Antonio, Texas
Collins, Harold W., Detroit, Mich.
Cogan, Charles M., Schenectady, N. Y.
Conlee, Carlton N., Chicago, Ill.
Cory, George L., New York, N. Y.
Covington, Paul T., Brooklyn, N. Y.
Cowdery, C. A., Bridgeport, Conn.
Craigen, Ewart G., Vancouver, B. C.
Cranage, Herbert A., Philadelphia, Pa.
Croft, John P., Lancaster, Pa.
Crossett, Martial C., Granite City, Ill.
Cuffe, Frederick W., Stratford, Ont.
Culver, Laurence R., Cambridge, Mass.
Cunningham, James A., St. Louis, Mo.
Curtis, George G., Wolcott, N. Y.
Curtis, Thomas R., Oak Park, Ill.
Dalton, William H., (Member), Salem, Mass.
Dauchy, Charles H., Cedar Rapids, Iowa
Day, J. W., Seattle, Wash.
Dearmin, H. Milton, San Francisco, Cal.
de Long, Oscar A., Jr., New York, N. Y.
Dennison, William O., Southbridge, Mass.
Devries, Joseph R., Holtwood, Pa.
Dobbie, Percy A., New York, N. Y.
Dovovan, William McK., E. Pittsburgh, Pa.
Douglass, Walter J., New York, N. Y.
Downer, Charles B., Schenectady, N. Y.
Dubson, John F., Spring City, Pa.
Ducey, Walter J., Jackson, Mich.
Duff, William P., New Haven, Conn.
Duguid, Russell H., Los Angeles, Cal.
Duncan, George R., Schenectady, N. Y.
Dutton, Thomas D., Boston, Mass.
Ellman, Jacob I., Philadelphia, Pa.
Ellsworth, Charles DeR., St. Louis, Mo.
England, Glenn L., Stockton, Cal.
Engquist, Victor E., St. Paul, Minn.
Erb, Henry G., Providence, Pa.
Estabrook, Harry E., New York, N. Y.
Ewing, Edward R., Boston, Mass.
Fee, Herbert McC., New York, N. Y.
Field, Ernest L., (Member), Boston, Mass.
Flachs, Emil E., St. Louis, Mo.
Forman, John S., Venice, Ill.
Forster, Cyril, Kingsville, Ont.
Franz, Hector A., Seattle, Wash.
Frost, Laurence E., New York, N. Y.
Fuller, Wallace J., Los Angeles, Cal.
Gabriel, Ralph F., Staten Island, N. Y.
Gardner, John E., Chicago, Ill.
Gemmell, Robert, Toronto, Ont.
Glacy, Edward W., Poughkeepsie, N. Y.
Gooderham, John W., New York, N. Y.
Grant, Allan Q., Chicago, Ill.
Gray, Burdette F., Hamilton, Ont.
Grayman, Jacob, Jr., New York, N. Y.
Green, Raymond V., Fulton, N. Y.
Gross, Jay C., St. Marys, Pa.
Grover, Frank I., Kansas City, Mo.
Griffin, Gilbert, Seattle, Wash.
Grimes, David, New York, N. Y.
Haines, Harold G., Detroit, Mich.
Hallock, Fletcher D., (Member), Boston, Mass.
Hannah, Paul D., St. Louis, Mo.
Hartmann, Frank J., New York, N. Y.
Hawley, Irving G., New York, N. Y.
Hedges, Charles O., St. Louis, Mo.
Herrick, Carl J., (Member), Oglesby, Ill.
Hershey, Carl G., Omaha, Neb.
Hiller, Carl A., Cincinnati, Ohio
Holgers, Ernest Z. N., (Member), New York, N. Y.
Holley, Arthur F., Raleigh, N. C.
Homan, Edmund L., W. Lynn, Mass.
Hooke, Robert G., Newark, N. J.
Horn, Charles, New York, N. Y.
Hough, William E., Oak Park, Ill.
Howard, John J., Chicago, Ill.
Hubbell, Harold, Camp Lewis, Wash.
Hugo, William J., Madison, Wis.
Hull, Alem P., Montgomery, Penn.
Hunt, Henry J., (Member), Madison, Wis.
Hyman, William N., New York, N. Y.
Irvine, Robert P., Cleveland, Ohio
Jackson, Wilson A., Detroit, Mich.
Jickling, Robert W., Winnipeg, Man.
John, George H., Detroit, Mich.
Johnston, J. McLean, (Member), New York, N. Y.
Jones, John W., Philadelphia, Pa.
Kallander, Carl H., (Member), Tacoma, Wash.
Katayama, Sigeru, New York, N. Y.
Katz, Henry A., Greensburg, Pa.
Kayler, Kenneth W., Wilkinsburg, Pa.
King, Harry C., Cincinnati, Ohio
Klinge, Richard A., Pasco, Wash.
Kluger, Albert, Jr., New York, N. Y.
Klugman, Gustav F., Jr., St. Louis, Mo.
Kneiszner, William T., New York, N. Y.
Knox, Adelbert D., New Haven, Conn.
Knox, Edward T., Richmond, Va.
Knut, Alexander, New York, N. Y.
Lawson, Frank I., St. Marysville, Cal.
Leighton, Charles L., Cushing, Okla.
Leinbach, Arthur R., Reading, Pa.
Lindstrom, L. O. B., Schenectady, N. Y.
Loomis, Alvin J., Seattle, Wash.
Lovatt, Harold S., Washington, Pa.
Macarow, Fred G., New York, N. Y.
MacDonald, George A., Los Angeles, Cal.
Mackay, William R., Baltimore, Md.
MacPadden, Augustus L., Schenectady, N. Y.
Mark, Francis P., Lancaster, N. Y.
Martin, Wendell L., Ft. Wayne, Ind.
Martinet, Eugene F., Cleveland, Ohio
Maruyama, Shigeru, New York, N. Y.
Mason, Williamson W., Elizabeth, N. J.
Mathewson, Dana, Chelsea, Mass.
Mauldin, Thomas R., Tallulah Lodge, Ga.
Maxwell, John F., Boston, Mass.
Mayer, Albert F., New York, N. Y.
McCullough, Lee W., New York, N. Y.
McGeoch, Rae, Toronto, Ont.
McKay, John A., Toronto, Ont.
McKee, Roscoe C., Akron, Ohio
McLoad, Kenneth, St. Louis, Mo.
Meineke, Otto H., (Member), Ambridge, Pa.
Messner, Roy L., Los Angeles, Cal.
Miller, George W., St. Paul, Minn.
Miller, James S., Jr., University, Va.
Miller, Rexwell D., San Francisco, Cal.
Minteer, Edwin C., Milwaukee, Wis.
Mitchell, James A., Hartford, Conn.
Moon, J. Leslie, Ft. Wayne, Ind.
Moore, Corman E., Cleveland, Ohio
Moore, Maurice A., Philadelphia, Pa.
Mulvany, Frederick A., Seattle, Wash.
Mumma, Robert W., Pottsville, Pa.
Muramoto, David K., Chicago, Ill.
Nagel, Harry L., St. Louis, Mo.
Naney, Edmund P., McGregor, Iowa
Neal, Albert G., Fitchburg, Mass.
Nelson, Arthur R., Camden, N. J.
Nesbit, Harvey D., Fresno, Cal.
Newell, Norman A., New York, N. Y.
Newton, Robert K., St. Louis, Mo.
Northrup, Burdette K., Ithaca, N. Y.
Oktay, Suleiman T., Akron, Ohio
Opperman, Richard H., Philadelphia, Pa.
Osburn, Orren E., Schenectady, N. Y.
Ostrom, Wellington R., (Member), Toronto, Ont.
Paduan, Nicholas, Houghton, Mich.
Pai, Ming Hsing, Schenectady, N. Y.
Palmer, Raymond J., Oxford, Mich.
Parker, Harry A., Nelson, B. C.
Paxton, Earl B., College Station, Texas
Payne, Lewis, Covington, Va.
Pearce, John H., Seattle, Wash.
Peters, Leo J., Madison, Wis.
Petty, James H., Kayford, W. Va.
Poey, Charles D., Long Island City, N. Y.
Poole, Foster M., Edwardsville, Ill.
Powers, Charles F., E. Pittsburgh, Pa.
Pradhan, Waman B., Schenectady, N. Y.
Quigley, Alexander, Toronto, Ont.
Rankin, David C., (Member), Chicago, Ill.
Ray, George H., St. Louis, Mo.
Rice, George R., Tacoma, Wash.
Rick, George D., Milwaukee, Wis.
Roberts, Donald E., Waukesha, Wis.
Rock, George D., Washington, D. C.
Rode, Norman F., Houston, Texas
Roehrich, William, Easton, Pa.
Rohrecker, Louis R., New York, N. Y.
Rose, Bernard, Brooklyn, N. Y.
Ross, John L., Pittsburgh, Pa.
Ross, William D., Seattle, Wash.
Rupp, Wellington, Olympia, Wash.
Ryan, Philip, Milwaukee, Wis.
Ryder, Milton P., Pasadena, Cal.
Sahlmann, Frank L., Schenectady, N. Y.
St. Clair, Ward K., Glasgow, Mont.
Sayre, William L., Philadelphia, Pa.
Schneider, William L., Brooklyn, N. Y.
Seal, Tong G., Buena Vista, Va.
Searle, William J., Jr., Philadelphia, Pa.
Sellke, Fred A., New Kensington, Pa.
Sellman, Albert H., Washington, D. C.
Shumaker, Raymond L., Xenia, Ohio
Sidenfaden, Oscar L., Schenectady, N. Y.
Siegfried, Joseph A., Allentown, Pa.
Singer, Leslie R., (Member), Kansas City, Mo.
Smiddy, Harold F., Pittsburgh, Pa.
Smith, Lansing T., Jr., Huntsville, Ala.
Smith, Stanley H., Seattle, Wash.
Smith, Thomas I., Omaha, Neb.
Sovik, Robert A., New York, N. Y.
Spence, Payton W., New York, N. Y.
Spielman, Milton H., (Member), Cleveland, Ohio
Spofforth, Walter, St. Paul, Minn.
Spratley, James B., Norfolk, Va.
Starbird, Levi C., Fayetteville, Ark.
Steerup, Godfrey, Chicago, Ill.
Stein, Herman K., Batavia, N. Y.
Stewart, George R., Chicago, Ill.
Stillwell, Walter I., New York, N. Y.
Stout, Melville B., Wilmerding, Pa.
Strong, John S., Madison, Wis.
Stryker, Norman R., New York, N. Y.
Sullivan, R. H., Rochester, N. Y.
Sullivan, Robert J. O., St. Johns, Newfoundland
Swain, Earl H., Amsterdam, N. Y.
Tanner, Alta R., Schenectady, N. Y.
Taylor, Charles C., Denver, Colo.
Taylor, Joshua W., Detroit, Mich.
Thalheimer, Ulrich S., San Francisco, Cal.
Thatcher, R. E., Seattle, Wash.
Thayer, Edward S., Seattle, Wash.
Tollison, Paul L., Waycross, Ga.
Toltz, Max, (Member), St. Paul, Minn.
Topham, Bertram J., Toronto, Ont.
Toussaint, Richard P., New York, N. Y.

Trant, James L., Ft. Wayne, Ind.
Trimingham, James H., (Member), Montreal, Que.
Turner, Clinton H., N. Reading, Mass.
Van Houten, Leslie P., St. Louis, Mo.
Van Nest, Percival C., Chicago, Ill.
Van Valkenburg, Kenneth H., New York, N. Y.
Vecera, Hugo, Brooklyn, N. Y.
Villiers, William R., Toronto, Ont.
Vincent, Frederick J., Toronto, Ont.
von Normann, Alfred G., Schenectady, N. Y.
Wall, J. J., Milwaukee, Wis.
Wallace, Thomas A., St. Louis, Mo.
Walls, Hoy J., Morgantown, W. Va.
Walton, Allyn K., New York, N. Y.
Wayts, Edward, Madison, Wis.
Weathers, Ethelbert W., (Member), San Diego, Cal.
Webster, Locke E., Seattle, Wash.
Weissman, Emanuel, New York, N. Y.
Wellford, A. L., Jr., Bluefield, W. Va.
Wellington, Hugo W. H., Boston, Mass.
Whipple, Wilder C., Seattle, Wash.
White, Russell G., Los Angeles, Cal.
Whitman, Allen L., Shippensburg, Pa.
Whitmore, Thomas, Spokane, Wash.
Whitton, William H., New York, N. Y.
Wilcoxen, Max W., Huntington, W. Va.
Wilkins, Roy T., Lynn, Mass.
Williams, Lester W., Chicago, Ill.
Williamson, Errol T., Chicago, Ill.
Willis, Olo C., Cleveland, Ohio
Wilson, Albert E., Toronto, Ont.
Wilson, William A., Bristol, Conn.
Wingard, Oscar, Los Angeles, Cal.
Wise, Raleigh J., Atlanta, Ga.
Wolking, Clifford G., New York, N. Y.
Wood, Claude O., Chicago, Ill.
Wood, Montraville, (Member), Berwyn, Ill.
Wooster, Lawrence F., Corvallis, Ore.
Wrigley, George, (Member) Greenville, S. C.
Wyman, Lee Edgar, Milwaukee, Wis.
Zerbe, Paris J., Philadelphia, Pa.
Total 306.

Foreign

Campbell, Archibald S., Newcastle, N. S. W.
Cargill, Charles G., Havana, Cuba
Dawson, Cecil, Erdington, Birmingham, Eng.
de Artigas, Jose A., (Fellow), Madrid, Spain
Guillan, Manuel, San Juan, P. R.
Hill, Edward P., Manchester, Eng.
Isaacson, Charles B., Barranco, Lima, Peru
Koehhar, Bishan D., Rampud, U. P., India
Pampin, Juan, Buenos Aires, Argentine Republic, S. A.
Patton, William C., Erdington, Birmington, Eng.
Pescod, Henry. T., (Member), Balboa, C. Z.
Rao, N. Nagarajo, Mysore, India
Smith, Thomas A., (Member), Havana, Cuba
Stair, D. H., Rancagua, Chile, S. A.
Stevens, Percy E., Calcutta, India
Thomas, Walter S., London, Eng.
Total 16.

STUDENTS ENROLLED DECEMBER 9, 1921

14060 Boorujy, George, Newark Technical School
14061 Pendleton, Albert H., Worcester Poly. Inst.
14062 Preston, Harold R., California Inst. of Tech.
14063. Howe, Glenn E., California Inst. of Tech.
14064 Hess, Edward R., California Inst. of Tech.
14065 Crissman, Robert J., California Institute of Technology.
14066 Bear, Ralston E., California Inst. of Tech.
14067 Woolfson, Henry M., Brooklyn Poly. Inst.
14068 Wong, Sam H., Oregon State Agri. Coll.
14069 Stebbins, Frederick O., Carnegie Institute of Technology
14070 Tesar, Joseph J., Case School of App. Sci.
14071 Manson, Rene, University of Cincinnati
14072 Hart, William C., New York Electrical Sch.
14073 Clark, Herbert S., University of Toronto
14074 Nimmcke, Frederick E., Brooklyn Poly. Inst.
14075 Nock, Herbert K., Mass. Inst. of Tech.
14076 Fink, Louis 3rd, University of Pennsylvania
14077 Stearns, Miner B., Univ. of Pennsylvania
14078 Linder, Clarence H., University of Texas
14079 Abbett, Gilbert W., Oregon State Agri. Coll.
14080 Kenrick, Gleason W., Mass. Inst. of Tech.
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Recent U. S. Government Reports

FEDERAL POWER COMMISSION

The first annual report of the Commission was issued for release on Dec. 10th. At the same time a complete statement was given concerning development of the Colorado basin with particular reference to its power resources.

INTERIOR DEPARTMENT

Geological Survey. "A Superpower System for the Region between Boston and Washington" Prof. Paper 123.—Electric operation of railways would cut down trackage requirements.—Annual report shows activity during year in topographic and geologic mapping, surveys and statistics of mineral resources, river and power surveys, stream measurements, and classification of public lands.

COMMERCE DEPARTMENT

Bureau of Standards. Meeting of Advisory Committee on nonferrous alloys.—Corrosion research.—Molding sand research. Gases in metals.—Specifications for enameled metal ware. Recommended specifications for pneumatic tires, solid tires, and inner tubes.—Characteristic soft X-rays from arcs in gas vapors.—Recent chemical publications.—Improved accuracy of American weights.

BUREAU OF MINES

Report of Investigation of Helium. These investigations cover Helium production at Petrolia, Texas; investigation of known and probable areas of Helium-bearing gas; Helium storage; Helium repurification after use in balloons; and investigations of gases and liquids at low temperatures, with particular reference to obtaining data for use in perfecting methods for separating Helium from natural gas by progressive selective liquefaction. These activities have been conducted under the authority of the Army and Navy Helium Board and the technical work was performed under the general direction of the Director of the Bureau of Mines. Funds were allotted from the Army and Navy.

Experiment Reports. The Pacific Experiment Station, Technology of Caustic Magnesia. The investigation of bituminous coal washing practises in middle western states being conducted by the U. S. Bureau of Mines, the Mining Department of the University of Illinois and the Illinois Geological Survey has been extended to include a survey of methods and use in Alabama. A study of coal washing problems in the State of Washington is being conducted by the Northwestern Experiment Station.

TREASURY DEPARTMENT

Public Health Engineering Abstracts: Street cleaning problems in Minneapolis.—The widening fields of Public Health.—The Sanitary Engineer, His Value in Health Administration.—Water Supply on the Niagara River.—Chlorination of Potable Water.—Reports on: Public Health Service schools on the Diagnosis and treatment of Tuberculosis. New U. S. Public Health Service Hospitals.

WAR DEPARTMENT

Chemical Warfare. Chemical Warfare and Industry.—French scientist declares chemical disarmament impossible.

Air Service. Airplane exports.—Aviation and newspaper publicity.—Aeronautical news from other countries.

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DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGS AND OTHER TRADE PUBLICATIONS

Street Lighting Transformers.—Bulletin No. 110, corrected. Describing various transformer types for street illumination purposes. Kuhlman Electric Co., Bay City, Mich.

Motors.—Bulletin No. 1300—Direct-current motors, No. 1500—Vertical motors, No. 1600—Back geared motors, No. 1900—Polyphase induction motors. Eck Dynamo & Motor Co., Belleville N. J.

Disconnecting Switches.—Catalog. High-tension indoor disconnecting switches; heavy-duty low-tension switches; switch locks; potheads. Thoner & Martens, 463 Commercial St., Boston.

Paper Pulleys.—Bulletin. Covering complete dimensions of paper pulleys to conform to the standards recommended by the Electric Power Club. Rockwood Mfg. Co., Indianapolis, Ind.

Copper Clad Wire.—Data Sheets. Containing wire tables and technical information, describing applications of Copperweld wire for overhead ground, telephone, series lighting circuits, railway suspension, police and fire alarm systems, signal wire; also loading tables for power conductors, river crossings and rural distribution. Copper Clad Steel Co., Rankin, Pa.

Coil Varnishing.—Bulletin. "Varnish Impregnation of Coils Wound with Enameled Wire." Acme Wire Co., New Haven, Conn.

Wires and Cables. A new edition of the "American Brand" leather-bound, pocket catalog. Described as a complete encyclopedia on weatherproof iron wire and bare copper wires and cables. American Insulated Wire & Cable Co., 954 West 21st St., Chicago.

Motors and Generators.—Bulletin No. 37A, d-c. "Multipolar" motors and generators. Peerless Electric Co., Warren, Ohio.

Starters and Speed Regulators.—Leaflets; data and prices. Sec. A-1, "Starter for d-c. motor (with low-voltage protection)." Sec. A-2, "Starter for single-phase commutator type motor." Sec. B-1, "Speed regulator for d-c. motor (armature regulation only)." Ward Leonard Electric Co., Mt. Vernon, N. Y.

Converters.—Booklets. "Wagner White Light Converters," for moving picture use. Wagner Elec. Mfg. Co., St. Louis.

Steam Turbine and Generator Units.—Bulletin No. 1119. For public utilities and industrial use. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Wiring Devices.—Catalog. 104 pages, describing Weber wiring devices,—sockets, switches, receptacles, rosettes, etc. Henry D. Sears, General Sales Agent, 80 Boylston St., Boston (11).

Condenser Tubes.—Booklet, "Tube Facts." Describes processes involved in seamless tubing manufacture and explains causes of condenser tube failure. Scovill Manufacturing Co., Waterbury, Conn.

Equipment for Textile Mills.—Bulletin No. 139. Power equipment and auxiliary apparatus. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

Lubricating Problems.—Monthly magazine devoted to problems encountered in lubricating machinery in all industries, mailed gratis. "Lubrication," The Texas Co., 15 Battery Pl., New York.

Employees Publication.—The San Diego Consolidated Gas & Electric Co. (Calif.) has commenced publication of a monthly magazine, "Glow," edited by and for its employees.

Process Timing and Signaling Systems.—Bulletin describing a line of instruments for use in manufacturing processes where the element of time is a factor, as in the heat treatment of steel, rubber, insulation molding, and for enameling, baking, etc. etc. The device automatically signals the predetermined time announcing the completion of a process. Stromberg Electric Co., Chicago.

Power Transformers.—Bulletin No. 1108. Allis-Chalmers Mfg. Co., Milwaukee, Wis.

NEW APPARATUS AND METHODS

Transformer Testing Set.—"Silsbee" portable set for making precision tests of current transformers in position, the actual working burden being connected in the secondary circuit of the transformer, so that the working ratio and phase angle are not disturbed during the test. The Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia.

Contact Wire for Sign Flashers.—Extra flexible wire, insulated with two reverse wraps of varnished cambric and a braid of cotton varnished. Lamp cord construction or rope twist (No. 36) soft annealed. Belden Mfg. Co., Chicago.

Oil Circuit Breakers.—Type D-17. Particularly adapted to automatic substations or where automatic reclosing of device is necessary because of small overall dimensions, relatively high interrupting capacity, non-splashing of oil and general operation without hazard.

Type F-10. High-capacity breaker of removable unit type, for central stations. Compactness permits insertion into most any cell formerly occupied by such apparatus, and character of construction provides for quick renewal if desired. Condit Elec. & Mfg. Co., Boston 27.

Photostat.—The Photostat Corporation of Rochester, N. Y., distributors of the Photostat, photographic copying machine, announces an all metal construction for its several sizes of this device, in which are incorporated also a number of new and improved features.

Condenser.—Low loss air condenser with permanent adjustment and rigid construction, for general laboratory use. Maximum capacity 1000 micromicrofarads. General Radio Co., Cambridge 39, Mass.

Tap Changers for Power Transformers. In large power transformers the shaft of the tap changer is brought through the stuffing box in the transformer cover and the operating handle placed outside to facilitate the operation of the tap changers, without removing the oil or the covers. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

MISCELLANEOUS

Wood Pole Preservation. The Valentine-Clark Company, Minneapolis, announces the opening of its pole butt preservation tanks to every consumer of poles, whether poles are purchased from this company or elsewhere.

Railway & Industrial Engg. Co.—A new district office has been opened at Cincinnati, 6 Greenwood Building, in charge of C. H. Mackelfresh, formerly connected with the Westinghouse Elec. & Mfg. Co.

The Jewell Electrical Instrument Co., 1640 Walnut Street, Chicago, has prepared a pocket memorandum book, for which fillers will be supplied every sixty days, for circulation among electrical engineers.

Okonite Company, New York.—John L. Phillips, Sales Engineer, has been transferred to the Atlanta office, 1513 Candler Building.

The Youngstown Sheet & Tube Co., Youngstown, Ohio, is distributing its 1922 calendars. They contain twelve 2-color illustrations 8 x 15 in., each showing an important operation in the manufacture of iron and steel. It will be sent to those interested upon receipt of six cents in stamps to cover cost of mailing.

The Packard Electric Company. New agencies. Baltimore, 1926 Edmondson Ave., in charge of O. T. Hall; Minneapolis, Metropolitan Life Bldg., in charge of White & Converse.